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A PROBE FOR THE MEASUREMENT OF HIGH SURFACE TEMPERATURES

GERALD A. STERBUTZEL

CORNELL AERONAUTICAL LABORATORY, INC.

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FOREWORD

This report was prepared by Cornell Aeronautical Laboratory, Inc., Buffalo, New York under USAF Contract No. AF-33(615)-1485. The program was monitored by W. E. Alexander, Air Force Flight Dynamics Laboratory, Research and Technology Division, Wright-Patterson Air Force Base, Ohio. The studies were started on 5 March 1964 and were completed on 1 July 1965.

At Cornell Aeronautical Laboratory, Inc., Gerald A. Sterbutzel was the project leader. John R. Shoemaker conducted the experimental tests and made significant contributions in probe sensor design and fabrication techniques. W.E. Alexander and W.R. Brown made important suggestions leading to the final design.

The manuscript of this report was released by the author June 1965 for publication as an RTD Technical Report.

This technical report has been reviewed and is approved.

Richard F. Hoener

Richard F. Hoener
Acting Chief
Structures Division

ABSTRACT

This report describes the design, operation and performance of a probe system with which temperatures can be measured quickly and accurately on a variety of surfaces. In operation the probe is touched to the surface and through its own sensor, heater and electronic servo system is automatically adjusted to the undistorted surface temperature. Extensive testing on a variety of materials (including alumina, stainless steel, titanium, Rene 41, disil coated molybdenum, disil coated columbium, zirconium, and quartz) has shown it generally to have an accuracy of better than 1/2%. The highest temperature measured successfully in intermittent steady state tests was about 2450°F (1343°C) and in transient tests was 2994°F (1645°C).

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I. INTRODUCTION

Aerodynamic heating problems of ever increasing severity have resulted from the development of advanced flight vehicles. Inherent in these aerodynamic heating problems are those of structural design which must take into account the complex effects of materials deterioration and of thermal stresses. In the necessary structural research, it is imperative that experimental work be employed. This requires the heating of important structural configurations in a manner which simulates typical aerodynamic heating flight paths. In carrying out studies of this nature, it has been found most convenient to heat typical structures by using radiation devices. In addition, it has been found most convenient in making temperature measurements of such structures to attach thermocouples to the surface of the heated system. Because perturbations of varying intensity may be caused by the attached external instrumentation, it is highly desirable to develop a device which is capable of measuring the true surface temperature at any point being so heated and which would not have the usual distortions generated by permanent installations. Such an instrument could then be employed very advantageously as a calibration device which can monitor intermittently or steadily the readouts of various points and serve as a standard. Of course, such an instrument could also be used to supplement or replace fixed thermocouple installations.

As a step toward satisfying need for such an instrument, Cornell Aeronautical Laboratory developed a surface temperature probe capable of operating from ambient to more than 1000°F with an accuracy of 3/8% and a normal time constant of the order of 0.1 seconds. This instrument has the capability of operating on a variety of materials, without modification of the monitored surface, in any position of orientation and without undue shadowing effects. A complete description of the 1000°F system is given in:

> Sterbutzel, Gerald A. et al., A Probe for the Instantaneous Measurement of Surface Temperature, RTD-TDR-63-4015, September 1963.

Because of the success of the 1000°F (538°C) instrument, it was decided to try to extend its range to 3000°F (1649°C) at an accuracy within 1/2%. This report describes the principles involved and the progress made in advancing the probe performance from the 1000°F level established with the first probe toward the 3000°F goal.

II. THE BASIC PRINCIPLE

The measurement of surface temperature is extremely difficult because of the basic requirement that any measuring device must not distort the measured local temperature by its presence. Thermocouple wires attached to a surface cause local heat flow by conduction within its leads thereby modifying the point of measurement. When radiation heating is used, the radiation characteristics of the thermocouple wires can easily create additional perturbations.

The principle used to eliminate these objections was that of using a sensor which when touched to a point on the surface to be measured is automatically controlled so that there would be no local heat flow. Obviously, with no local heat flow, the accurate temperature at the point of contact can be recorded. In order to achieve this type of performance, differential and readout thermocouples are used to form the sensor. At the sensor is a heater whose output energy is controlled by an electronic servosystem. When the probe tip is touched to the surface, a temperature difference is detected by the differential thermocouple which instantaneously is reduced to zero through the heater-control system. As the differential thermocouple is automatically adjusted to zero, an accurate readout is taken from the thermocouple readout system. To prevent temperature destortion patterns in the measured surface, (particularly in the low conductivity materials) a fast response is necessary. It is therefore imperative that the sensor be very small and of almost negligible mass. In addition because of the necessity to use under radiation heating environments, it is necessary that the sensor be attached to a thin probe to prevent excessive shadowing. The developed system meets these requirements.

III. THE DESIGN OF THE HIGH TEMPERATURE SYSTEM

The major components of the system are probe, power controller, temperature recorder and D.C. power source as shown in the block diagram of Figure 1 below:

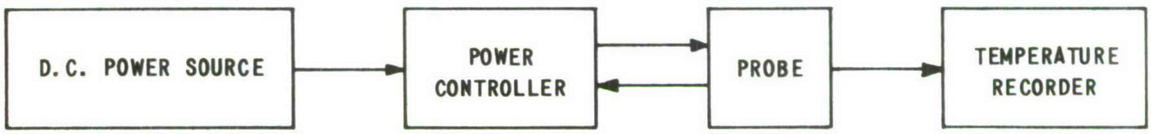

Figure I BLOCK DIAGRAM OF THE SYSTEM

In operation, the probe is touched to a hot surface and senses a temperature unbalance indicating heat flow at its sensor. The unbalance signal is amplified by the D.C. Amplifier within the power controller which then calls for power from the D.C. power source. This power at any instant is proportional to the magnitude of the unbalance of the sensor. The power into the heater heats the probe tip to correct the unbalance. As the unbalance approaches zero, the power controller diminishes the energy output to the heater until a "steady state"-no heat flow condition exists at the sensor. Once the no heat flow condition exists, the true surface temperature is indicated or recorded using a thermocouple at the sensor tip.

Each of the items in the present system is discussed individually below. The entire system is pictured in Figure 2.

1. Probe and Holder

The high temperature probe pictured in Figure 3 consists of a pure alumina sting and a sensor at its tip. The pure alumina sting contains six holes for lead wires to the holder. The sting is 0.190 inches in diameter and 12 inches long.

A cross section of the sensor is shown in Figure 4. It consists of a platinum, cylindrical "T" unit to which is attached three thermocouple leads as illustrated. This system permits a readout of the temperature and in addition gives a signal of the magnitude of any temperature unbalance between the differential thermocouples at the tip and at the base of the T. It also contains a spiral wound platinum-13% rhodium heater which is energized by current metered from the power controller. The heater wire is wound around a very small (0.045" od - 0.013" id) ceramic tube. Good thermal contact as well as adhesion among all parts is provided by thorium oxide cement.

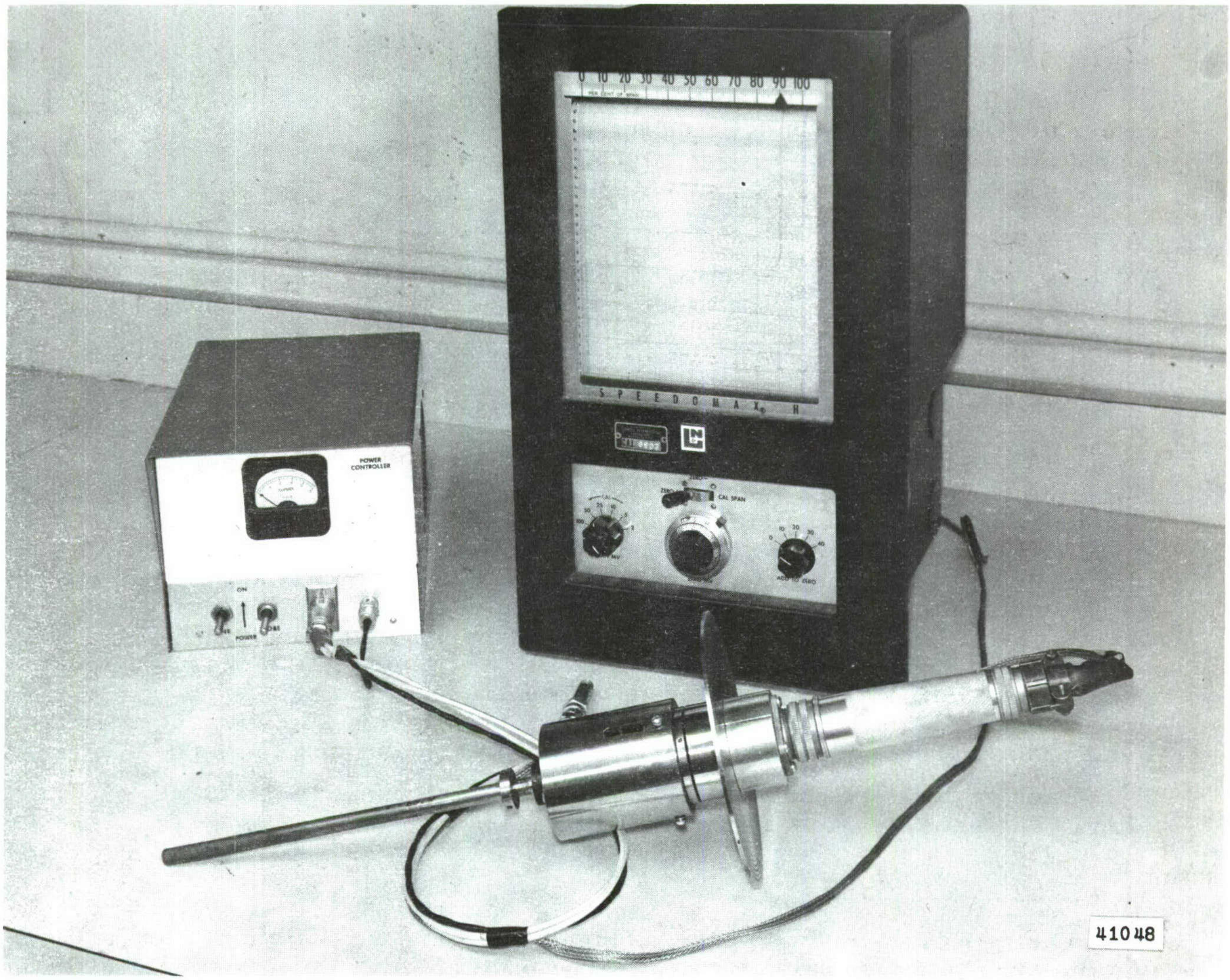

Figure 2 THE HIGH TEMPERATURE SYSTEM

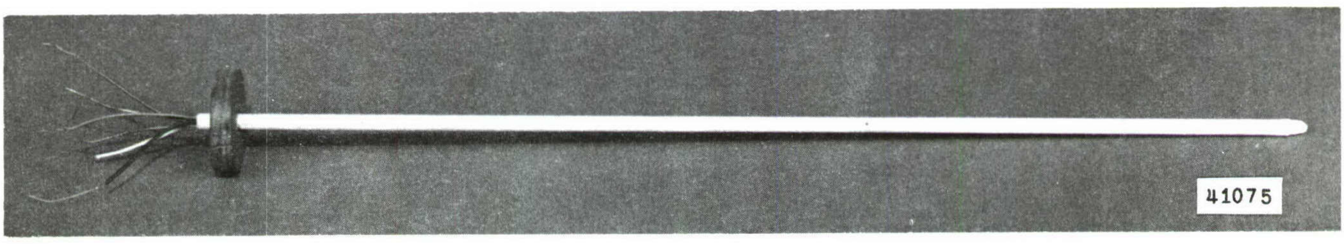

Figure 3 THE PROBE BEFORE INSTALLATION INTO HOLDER

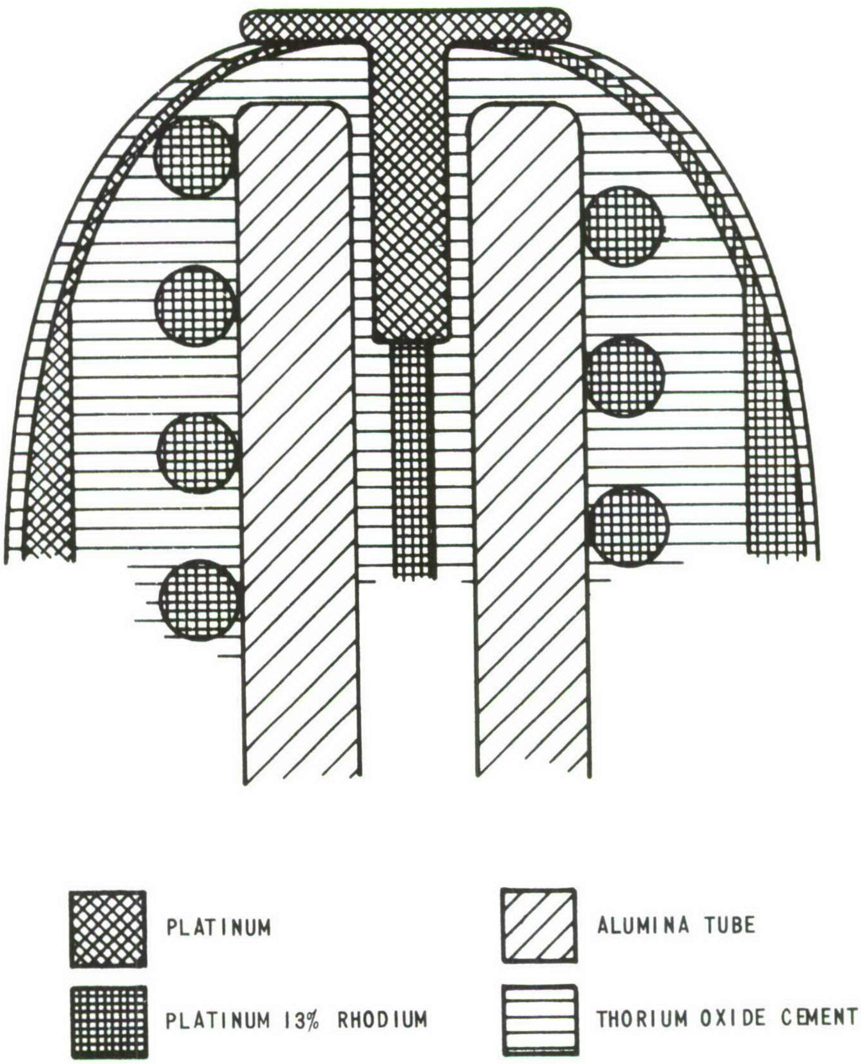

Figure 4 CROSS SECTION OF THE SENSOR

As can be observed from Figure 2, the probe is handled and is encased in a metal holder. The purpose of this holder is to protect the operator's hands from the high temperature and secondly to protect the probe from thermal shock damage in coming instantly in close proximity with very hot elements of the radiation heating facility. The holder is made of stainless steel with the tip of the holder having a six channel annulus through which nitrogen or water is passed. This keeps the holder tip to temperatures like those illustrated below when the heaters are at 3000°F.

50 psi Nitrogen	
Distance from tip, inches	Temperature °F
tip	863
.5	610
1.0	520
1.5	440
2.0	410
2.5	400
3.0	380
3.5	340
4.0	300
4.5	270
5.0	240

25 psi Nitrogen	
Distance from tip, inches	Temperature °F
tip	1310
.5	1170
1.0	1010
1.5	970
2.0	940
2.5	920
3.0	900
3.5	850
4.0	780
4.5	700
5.0	640

Appreciably lower temperatures result when water at 1000 ml per minute is used.

The holder has a spring within the handle to enable the probe to be extended and retracted. The probe when fully extended is 1 inch from the tip of the holder. A closer view of the holder is given in Figure 5.

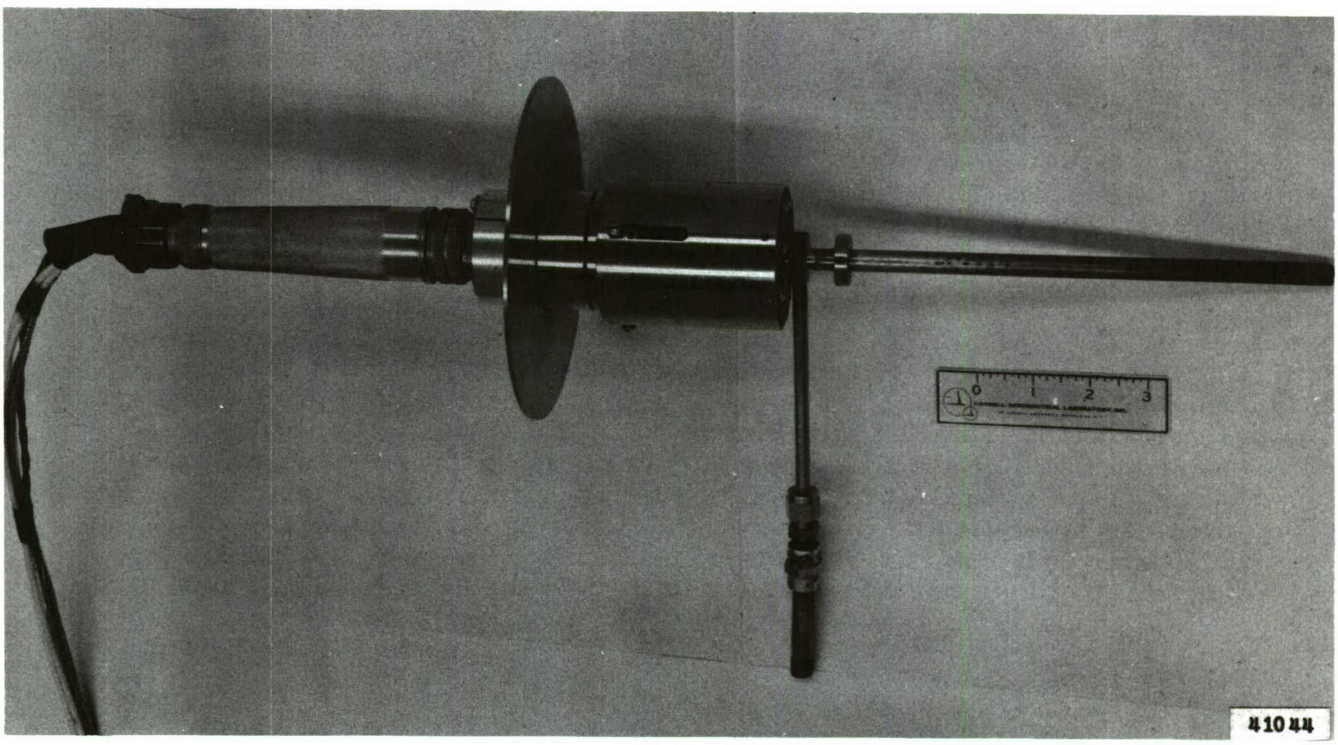

Figure 5 PROBE HOLDER

2. Power Controller

The circuit diagram of the power controller is shown in Figure 6. This unit utilizes a plug-in Philbrick D.C. Amplifier and power supply. The power controller unit weighs 7.5 lbs. and measures 6" x 7" x 9".

Transistors were selected for the two stage power control package because of their ability to supply a high power to low impedance loads. The input stage is primarily a driver stage employed to control the base current of the output stage. Overall, this unit is capable of supplying more than 60 watts of continuous power at 6 volts applied emitter-collector voltage. To some extent, the power amplifier unit is an electronic switch in that conduction is achieved only when transistor input variable potentials are overcome. The threshold level at which this "switch" closes is predetermined by the bias voltage control on the input stage. To preclude thermal run away, the transistors are mounted on heavy heat sinks that are in turn forced-convection cooled. This feature assures sole control by input error signals at all times. Although the preamplifier responds to signals of either polarity, the power control unit responds only to positive polarity signals. Hence, only error signals requiring positive probe heating elicit control circuit response. Since the probe design embodies very low thermal lag in the thermal element, this feature ensures absolute power cutoff as soon as the error signal reverses polarity and thus enhances system stability.

Figure 7 shows a inside top view of the power controller package.

3. D.C. Power Source

The basic D.C. power source is a six-volt wet cell battery. This is connected to the controller through a switch which permits the choice of two, four or six-volts but 4 volts have been used for most system evaluation tests. The D.C. power could also be supplied by a rectifier which operates from a 110-volt A.C. line if desired. The use of a rectifier does have a potential of being much handier to use and once its stability is proved probably should be incorporated.

4. Temperature Readout

For reading the probe sensor temperature, a Leeds and Northrup Model H Speedomax strip chart recorder was used for most of the experimental work. For the fast response experiments, a Minneapolis-Honeywell Visicorder 906A Oscillograph was used and in much of the experimental work, the magnitude of the temperature unbalance was read on a Tektronix 502 Oscilloscope.

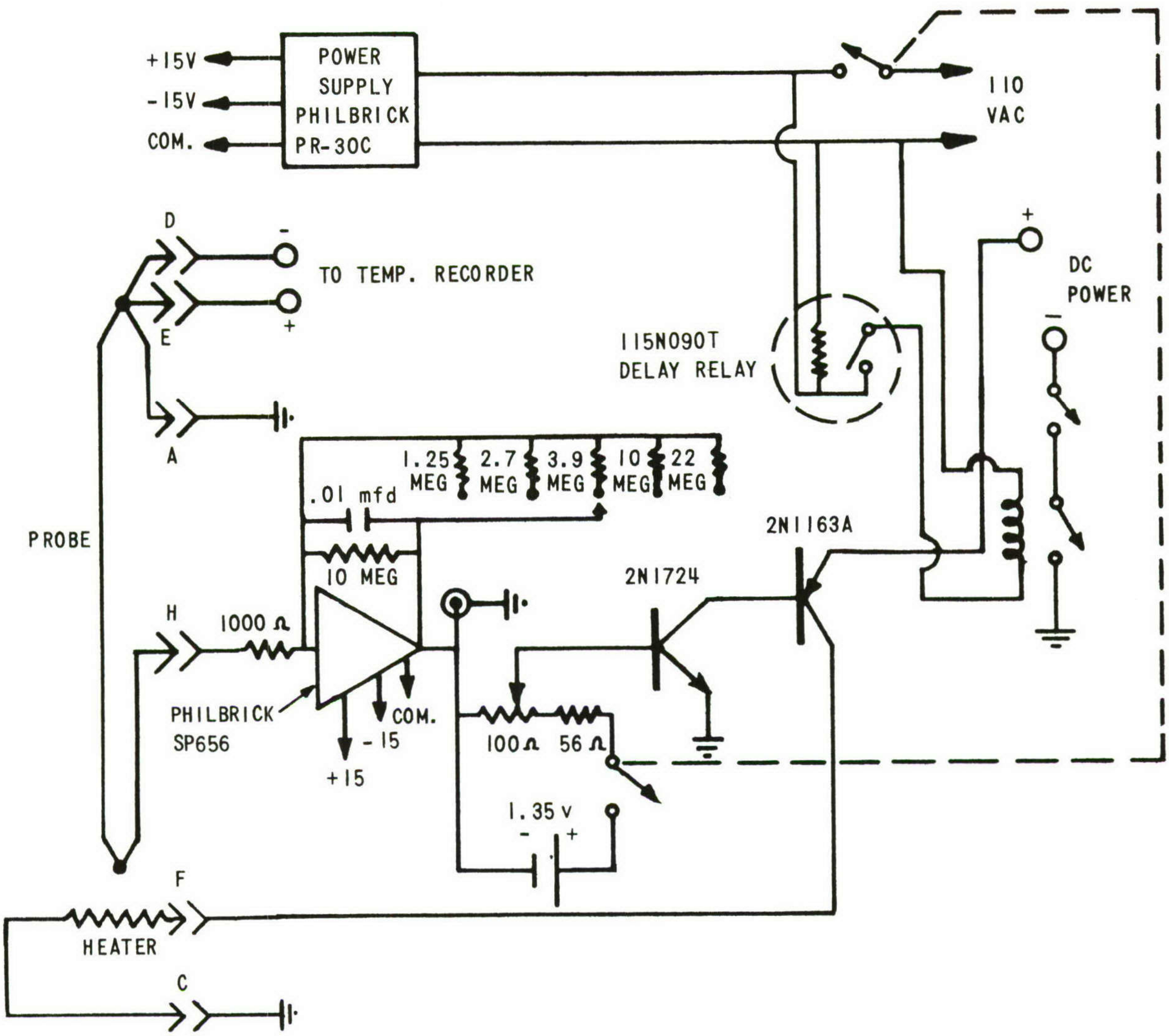

Figure 6 POWER CONTROLLER WIRING DIAGRAM

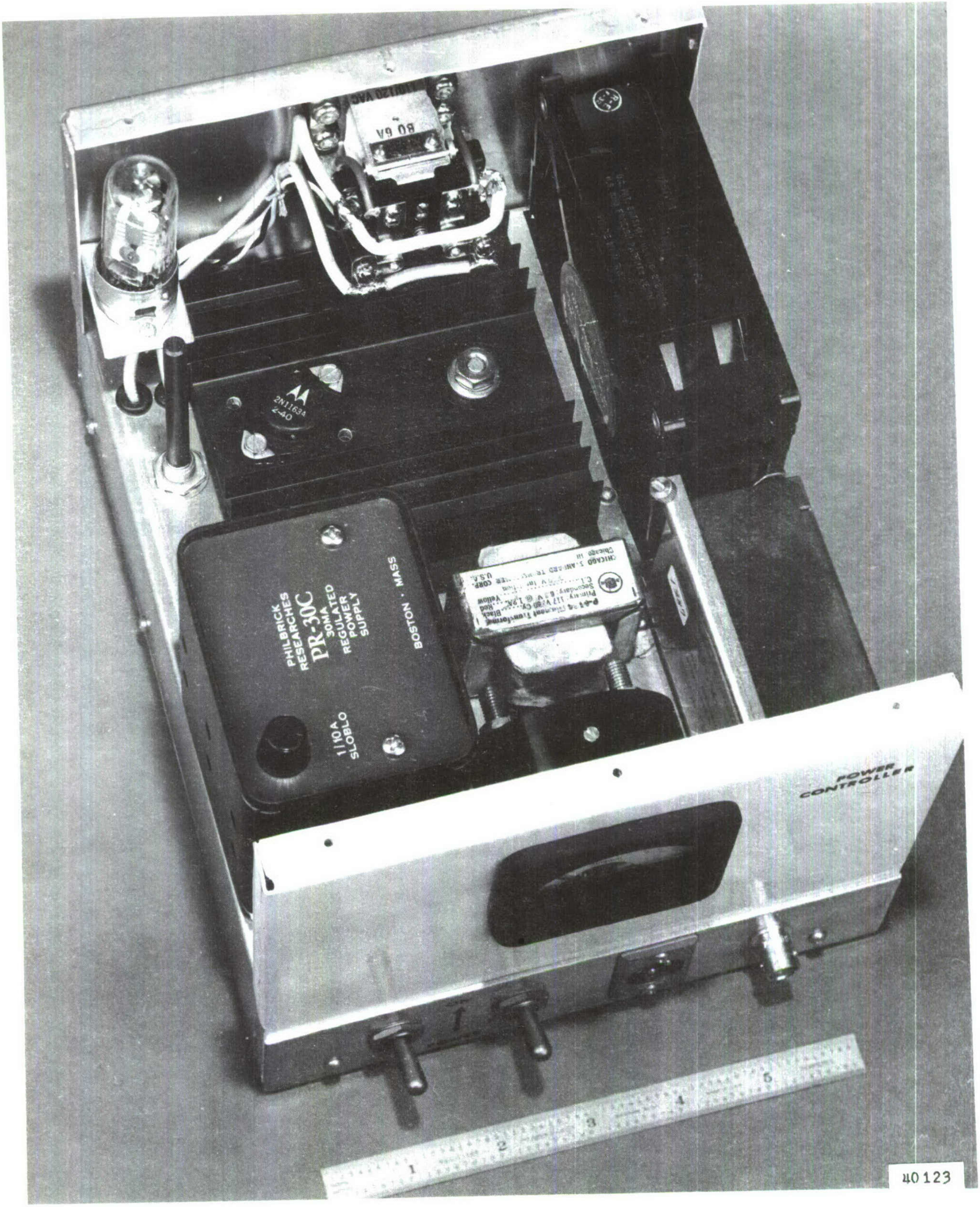

Figure 7 THE POWER CONTROLLER

5. Auxiliary Equipment

For much of the initial experimental work in developing the sensor, a standard surface temperature heater was fabricated. It is a one inch-diameter stainless steel cylinder capable of operating at temperatures slightly above 2000°F. This heater is rheostat controlled and provides a variable uniform surface temperature when any rate of changes are small. A calibrated thermocouple was installed very close to the surface of the cylinder at its center.

To simulate the effects of a radiation heat source, a small radiation heating furnace (Figure 8) consisting of four 6 x 0.8 x 0.125" carbon heating elements was employed. These elements were located with their flat sides parallel to the surface to be tested in such a manner to permit a uniform heat flux. Test plates 4" x 4" can be accommodated. A power level of 6.4 kilowatts is required to maintain a titanium plate at 2900°F. The carbon heating elements are 2 inches from the test plate. The heating units are surrounded by a firebrick insulated box whose metallic outer surface is water cooled. A hole in the insulated furnace cover allows the probe to be inserted and touched to the test plate. The test plates are varied in size from 1 x 3 x 0.065" to discs of 1.5 inches in diameter. The thicknesses vary depending upon individual test material. Platinum-platinum, 13% rhodium thermocouples were carefully installed in each plate under the surface away from the radiant heat source. On some specimens, thermocouples were also attached to the surface. For each material, the thermocouples were calibrated to assure their reproduction of accurate temperatures. Further, the method of installation was such that heat losses in the thermocouple leads would be minimized. The carbon heating elements are protected by a nitrogen or argon atmosphere. The test specimens are in an air environment.

In order that all tests be run in a comparative manner, the contact pressure for each operation was carefully controlled by a lever-fulcrum unit on which weights could be attached. A weight as high as 567 grams was used. Weights much lower than this have also been used with good results. For example as little as 133 grams gave satisfactory results. Because the tip has such a small area, normal hand pressure will produce a rather high force per unit area. Excessive pressure should be avoided to prevent damage to the sensor and the measured surface.

Thermocouples are calibrated by utilizing the furnace pictured in Figure 9. A cross section of this furnace is also shown in Figure 10. By utilizing this equipment, thermocouple calibrations at the melting points of various metals can be carried out. The probes can be calibrated by installing the finished sensor tip in the furnace and permitting sufficient time so that any gradients in the probe are eliminated. Results of the calibrations show that in every case the emf output was within the tolerances claimed by the manufacturer.

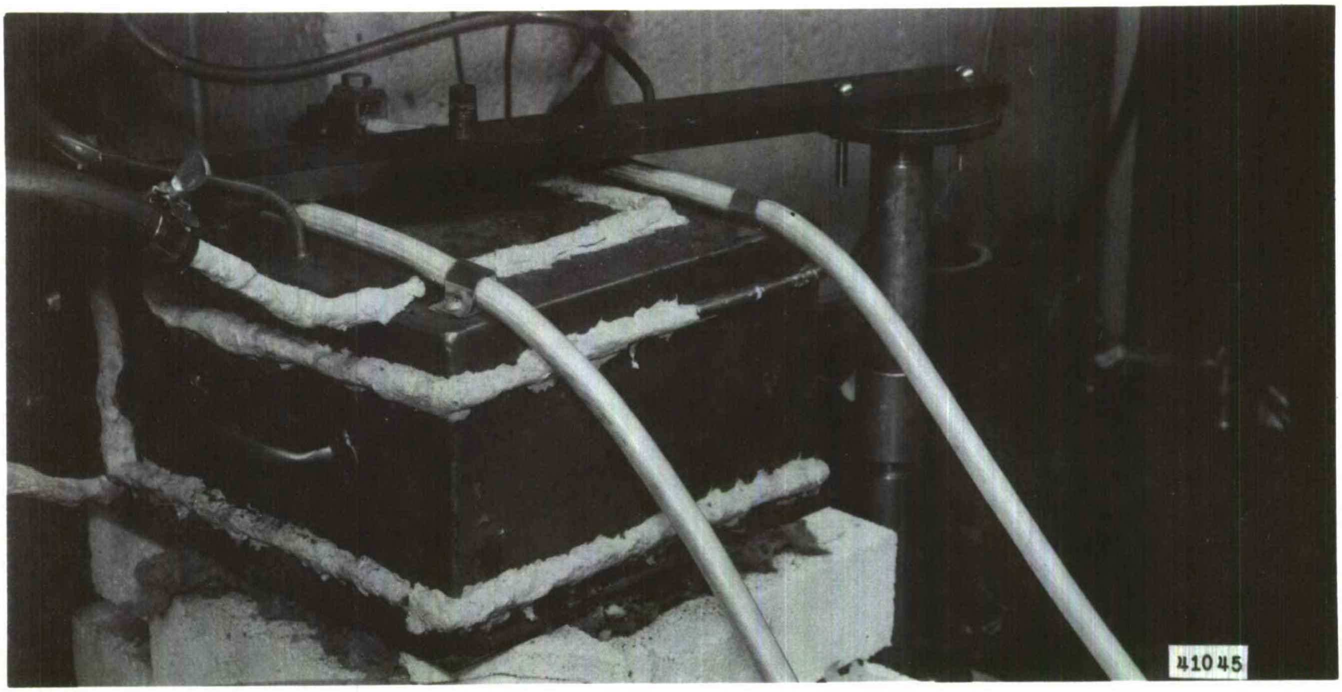

Figure 8 RADIATION FURNACE

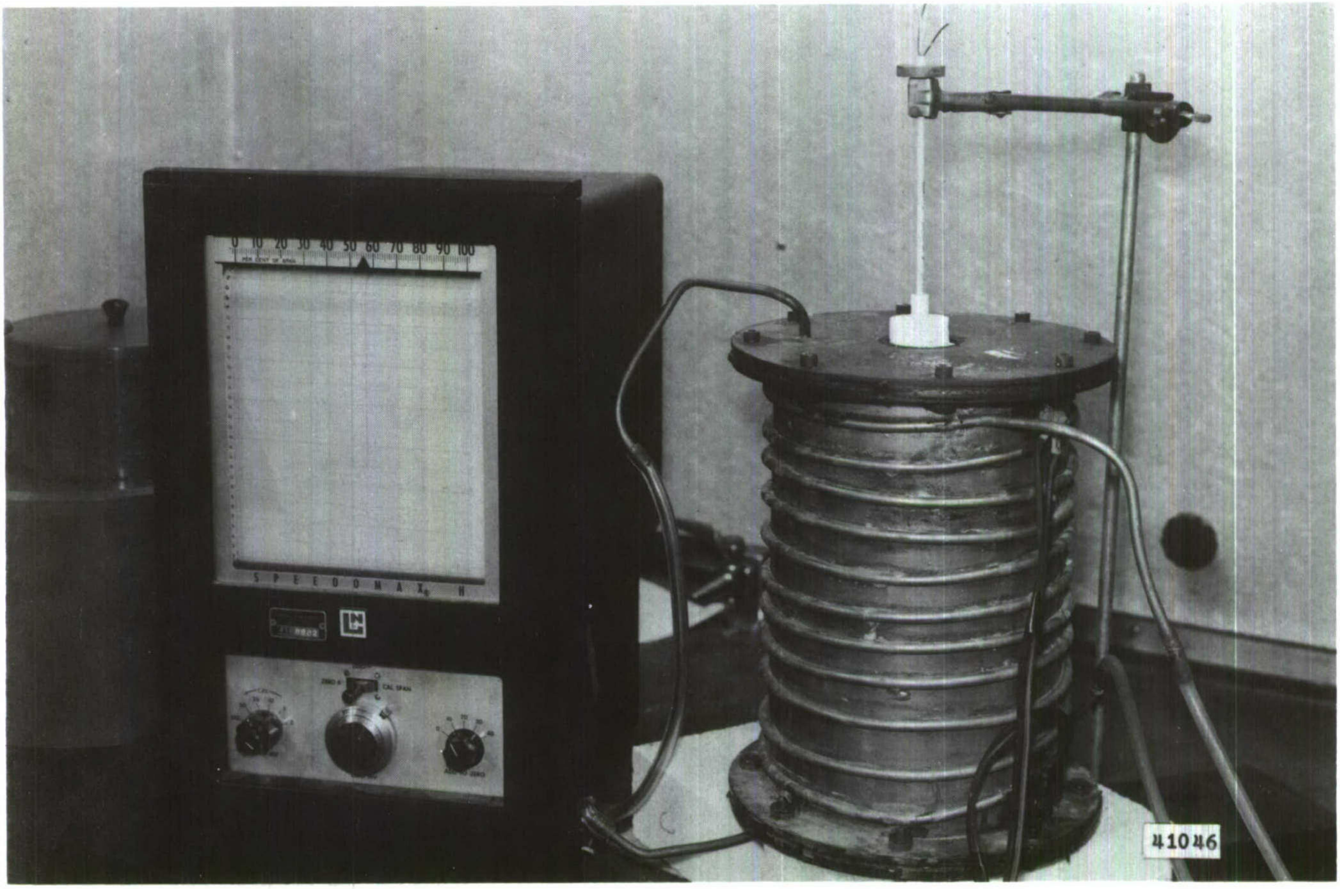

Figure 9 CALIBRATION FURNACE

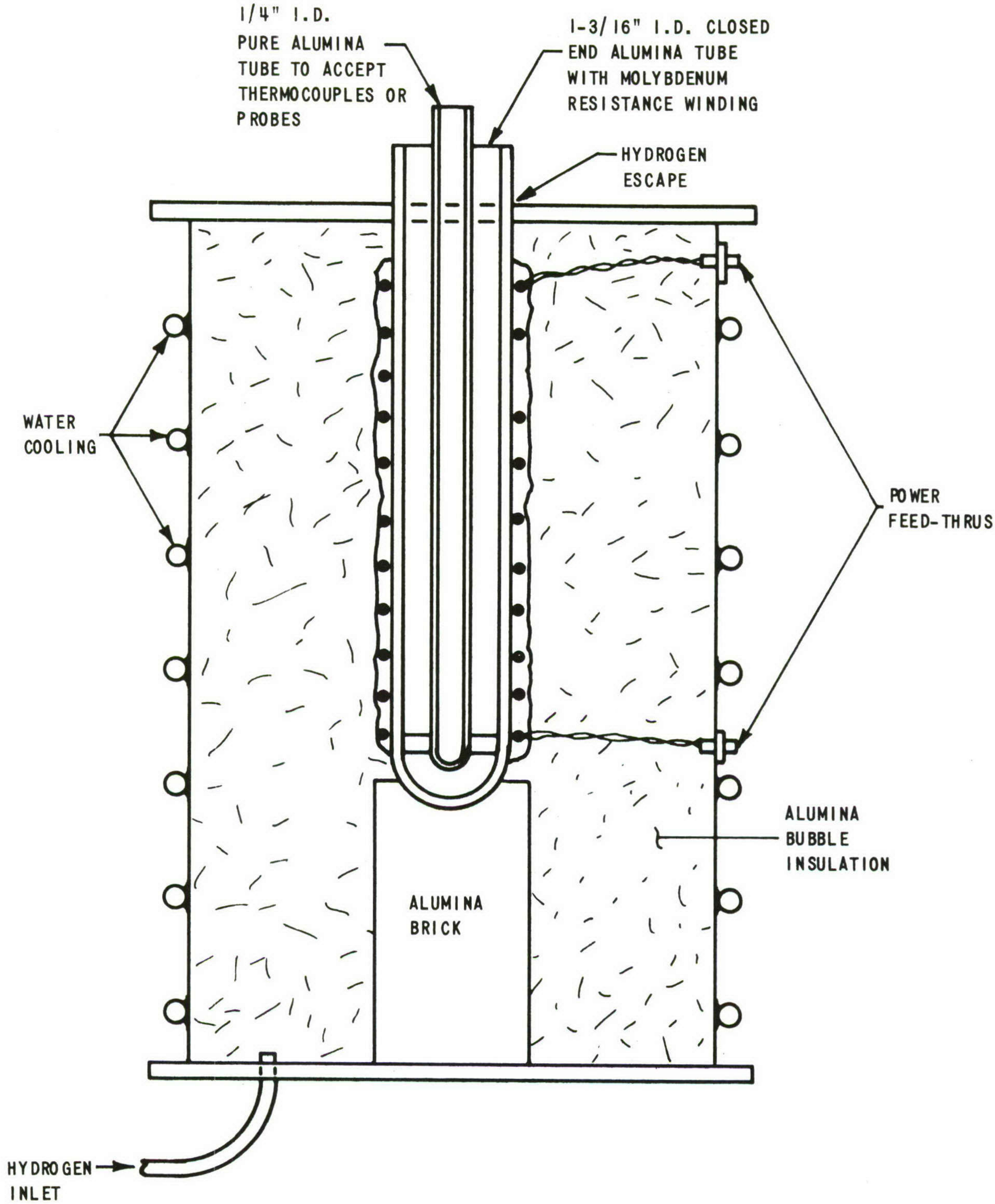

Figure 10 CROSS-SECTION OF CALIBRATION FURNACE

IV. OPERATION OF THE SYSTEM

Connect the components of the surface-temperature measuring system as shown in the schematic of Figure 1. Cable connectors and chassis receptacles are arranged so that wrong connections cannot be made inadvertently.

To activate the system, the following sequence of operations is performed in the order listed.

1. Assure that probe switch is "OFF".

2. Turn Power Controller Line Switch "ON".

3. Allow 2 minutes for equipment to stabilize.*

4. Turn probe switch "ON".**

5. Apply probe to surface to be measured.

Proper operation may readily be determined by observing the meter for a slight movement when touching the probe sensor to a warm object.

The BNC connector at the back of the power controller can be used to monitor its operation.

* A thermal delay relay automatically prevents power to the probe for 90 seconds. Don't be alarmed by relay actuation noise.

** If ammeter shows a significant deflection after probe switch has been turned "ON" for the first time, turn it off for an additional minute and repeat if necessary. This will rarely, if ever, happen.

Note: A recommended gain and threshold amperage setting is given for each probe. These adjustments should be made when each new probe is installed.

V. PERFORMANCE CHARACTERISTICS

During the entire development portion of the program, effort was made to determine the accuracy and response characteristics of the probe. As the development approached its present state and it was possible to at least temporarily freeze the design of the probe, a number of tests were made to determine the response and accuracy characteristics as well as practical operational characteristics. Figure 11 shows a test in progress. The

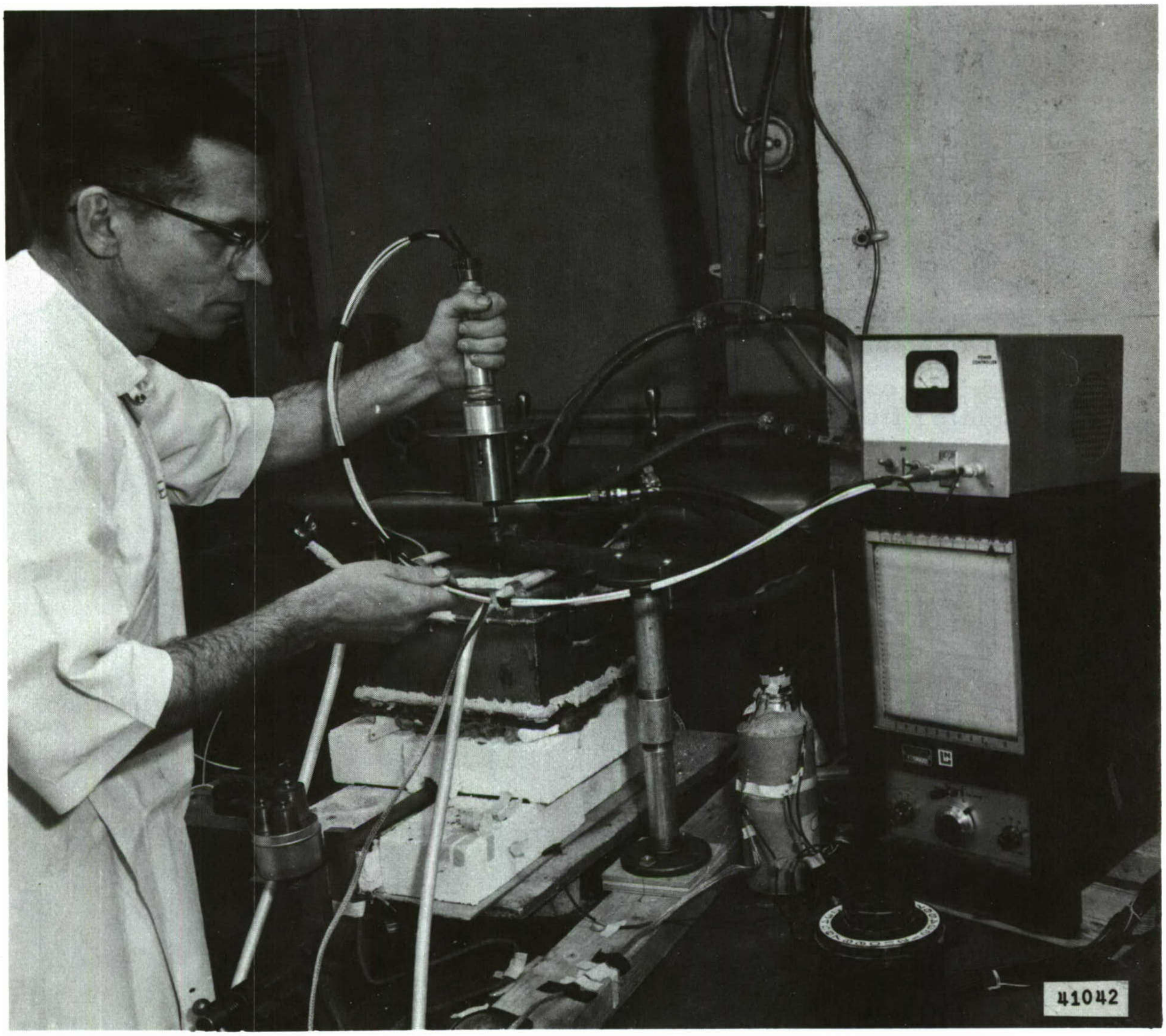

Figure 11 PERFORMANCE TESTING

following types of tests were conducted:

1. Steady State

   These are tests in which the probe sensor was in continuous contact with a test material at relatively constant temperature.

2. Intermittent Steady State

   These are tests in which the probe sensor was contacted intermittently for short duration to a test material at relatively constant temperature.

3. Transient

   These are tests in which the probe sensor was in continuous contact with a test material of increasing temperature.

4. Intermittent Transient

   These are tests in which the probe sensor was contacted intermittently for a short period to a test material of increasing temperature.

Tables of the test results are given at the end of this report starting on page 22. For each table is given pertinent information relative to that individual test. For example the material on which the test was made, the specific probe which was used, the gain set in the power controller, the voltage used for the D. C. power source, and the threshold setting on the power controller are all given. The probes used for all these tests are the X series which is the present "frozen" design. The number following the X is the serial number of the individual probe. The times listed in the Tables are the times from contact. The plate and probe temperatures are those read by the plate and probe thermocouples and the deviation is simply the difference between the probe and plate temperature. A minus in the deviation indicates that the probe is reading lower than the plate.

The results of the testing are summarized briefly below and that is followed by greater detail with data substantiation.

1. <u>Summary</u>

   The system has a performance capability of:

   a. Accuracy generally one half percent or better.

   b. Successful operation on all metals and non-metals tested including stainless steel, disilicide coated molybdenum, disilicide coated columbium, Rene 41, alumina, quartz, zirconium and titanium

c. Operation in both intermittent and continuous contact.

d. Operation on surfaces at steady or transient temperatures.

e. Operation governed by an initial time constant of the order of less than a second. A total period of from 3 to as much as 10 seconds from time of contact is generally assurance that temperatures are read within 1/2%.

2. Accuracy

At the beginning of this development an accuracy of one half percent was set as a goal for the measurement of surface temperatures ranging from 1000° to 3000°. This is equivalent to a deviation at full scale of 15° F. For practical purposes this performance level has been reached and in almost all cases surpassed. This is observable in the data presented at the end of this report and in the following statements.

a. Stainless Steel (316)

Tests on stainless steel have been conducted throughout the entire range up to the capability of stainless steel to withstand the temperatures and oxidation effects. As can be noted from the Tables at the end of this report, the intermittent, one-minute, steady-state tests produced a maximum deviation at various temperatures of

Temperature	Deviation
1065° F	4° F
1522°	9°
2050°	0°
2262°	4°

As noted in the tables, a change in stainless steel plates had to be made because of the deterioration at 2262°. Such a change apparently did not affect the results of the probe readings. Long time testing at between 2050° and 2100° produced superb accuracy results. During this testing, the maximum detectable deviation was about 3° F.

b. Titanium

The accuracy of the probe when tested on titanium was also excellent. For example the maximum deviation in tests at about 1050° was 2°. At approximately 1530°, the maximum deviation was also 2°. At just below 2100°, the maximum deviation was -10° but as time progressed the accuracy improved. In these last tests the plate did deteriorate with a white oxide being formed on it and the probe tip adhered to the plate.

c. Rene 41

A variety of accuracy tests were made on Rene 41 including a partial evaluation of variation of contact load. Contact loads of 567 grams and 267 grams were tested. Decreasing the load to 267 grams made no apparent difference and perhaps even improved performance a slight amount. Accuracies were excellent once a steady state was reached and deviations were generally less than 5° at temperatures ranging through 1500°F. In a series of tests at 2085°, a maximum deviation of 15° was recorded. Additional tests should be made in this area to know whether some contact point sensitivity was present in this test which affected apparent accuracy.

d. Alumina

A large number of tests were made on alumina with again generally good accuracy results. For instance, the first tests at just over 1000° showed a maximum deviation of 2°F. At just over 1400°, the maximum deviation was 6° and at just under 2000°, the maximum deviation was 8°.

Several of the initial tests on alumina showed considerably more deviation than was found later in the tests. At first this was believed to be some failure on the part of the probe to read appropriate temperatures. It was decided, however, that the alumina (because of its low thermal conductivity) was unusually sensitive to precise positioning and therefore a very minute variation in location with relation to the monitoring thermocouple could cause these errors. Note that in the later tests, there was a consistency toward excellent accuracy.

The tests on alumina were also extended to relatively low temperatures. As a matter of fact, temperatures as low as 470° were tested with excellent results.

In run 30 (Table 4), the probe was tested in a slow transient condition. Thirty four minutes were allowed to bring the plate from about ambient temperature to 2686°F. Because of the transient condition and the low thermal conductivity of the alumina, the front of the plate is shown to be at a different temperature than the rear of the plate where the monitoring thermocouple is attached. As the two sides of the plate approached equal temperatures, the deviation became zero. During this test run, a temperature of 2686°F was reached with negligible deviation. At this temperature, the test had to be discontinued because of a failure in the auxiliary equipment. Run 31 (Table 4) was also a continuous contact transient test. In this test, a probe temperature of 2994°F was reached.

e. Disil Coated Molybdenum

Six tests were conducted on disil coated molybdenum using a regular X series probe with a very thin rhodium cap to protect its tip from the disil coating. (This was necessary because platinum is readily attacked by the disil coating.) Three of these tests were made with a probe loading of 133 grams while the other three was made with a loading of 267 grams. In each case, the lesser load produced a very small increase in deviation. The deviation could probably be neglected in that it was generally about 5°. In each case the lesser load produced a slightly higher temperature. The reason for this is not understood.

In all cases, the performance of the probe on disil coated molybdenum appeared to be excellent and in no way varied from the performance on the other materials.

f. Disil Coated Columbium

Four tests were made on disil coated columbium, three with a loading of 133 grams and one with 267 grams. No difference in the effect of loading was noted. In the first three tests, the performance of the probe was superb. During run 4, a transient temperature test from somewhat over 1000° to over 2270° was conducted. Performance of the probe was again good but it can be noted in the table for run 4 that the deviation did rise to about 26°. Although it cannot be evaluated precisely, it is believed that most if not all of this deviation is caused by a temperature difference from the front surface of the plate to the thermocouple location due to the transient changes in the probe with time. Note that as the rate of temperature rise slowed, the deviation decreased.

g. Zirconium

Eleven tests were made on zirconium again using loadings of 133 and 267 grams. The test performance again was comparable to that determined from the other materials.

h. Quartz

Being a transparent material, quartz is particularly difficult to instrument with standard thermocouples for knowledge of monitoring surface temperatures. This is true because the radiation effects on the thermocouple wires were certainly different than on the quartz. It is essentially necessary to have a thermocouple of infinitesimal cross section in order to diminish the perturbation which may result. In the test plate used for these tests, a thermocouple was attached to the rear face with the cement used being across the entire bottom of the plate making it semiopaque. Also a thermocouple was attached to the front face adjacent to where the probe was touched. This thermocouple required only a small amount of cement but it is believed that some perturbations were caused by its use. Three tests were made on quartz and each show quite a deviation from the permanently installed thermocouples. Although as time went on the deviation continued to decrease, the performance appeared not to have the time response as is normally found on other materials. After one minute, the results showed rather good accuracies.

Because in these tests it cannot really be considered that any one system is strictly correct, it is difficult to make a statement on probe accuracy. Because of the elimination of lead losses in the probe and the good conductivity across the interface, it is believed that the probe will perform accurately on a quartz plate. The probe of course is subject to reading the temperature that it "feels" and therefore can have a radiation component caused by reflections through the transparent surface.

3. Response Time

It is very desirable to have fast response characteristics in the surface temperature measuring probe because of the need to follow transiencies at times and to create negligible distortion of the temperature of the measured surface. In the design of a probe of this nature, a rather careful balance must be reached between the fragility of the probe and the response time. This is true because frequently to get high response, the mass must be minimized and this in turn leads to vulnerability to breakage or operational failures. Because accuracy is of paramount importance in the design, it was accentuated with response time being given at least temporarily a secondary consideration. In so doing, excellent accuracies have been achieved with some success also in time response. For example at the instant of contact, the time constant of the probe is certainly less than 1 second and frequently on the order of 1/2 second. To be sure that readings within the desired accuracy limits are taken, at least 5 seconds should be allowed. The required time for equilibrium readings, of course, can be observed on the recorder readout.

The response time of the very latest probe is appreciably better than the performance described above. This is illustrated in Figure 12 on the next page which shows the probe reaching a surface temperature of 1770°F in 2.2 seconds.

4. Shadowing

Experiments were conducted to determine the existance of a possible shadowing effect caused by the cooled probe holder. A stainless steel plate at an average temperature of 1800°F was used. The holder was adjusted to varying distances from the plate and changes from the steady state reading were noted. A steady state, maximum deviation was reached within 20 seconds after contact. The following maximum deviations were noted.

Distance from Holder Tip to Plate Inches	Maximum Deviation °F
0.25	-52
0.50	-37
0.75	-26
1.00	-10
1.25	-11

Operationally, it appears reasonable to keep the holder tip at 1 inch from the test surface. Because stainless steel has low thermal conductivity characteristics, it will undoubtedly show the worst shadowing effects of the metals tested.

No effect of shadowing of the extended probe was found on any of the metals tested. Some very slight effect may have been detected on alumina but this has not been proved. If it does exist, the maximum effect appears to be limited to no more than 3°F.

5. Longevity

To determine the longevity of the probe, a number of long-time tests were completed on alumina and Rene 41. The alumina tests are reported in

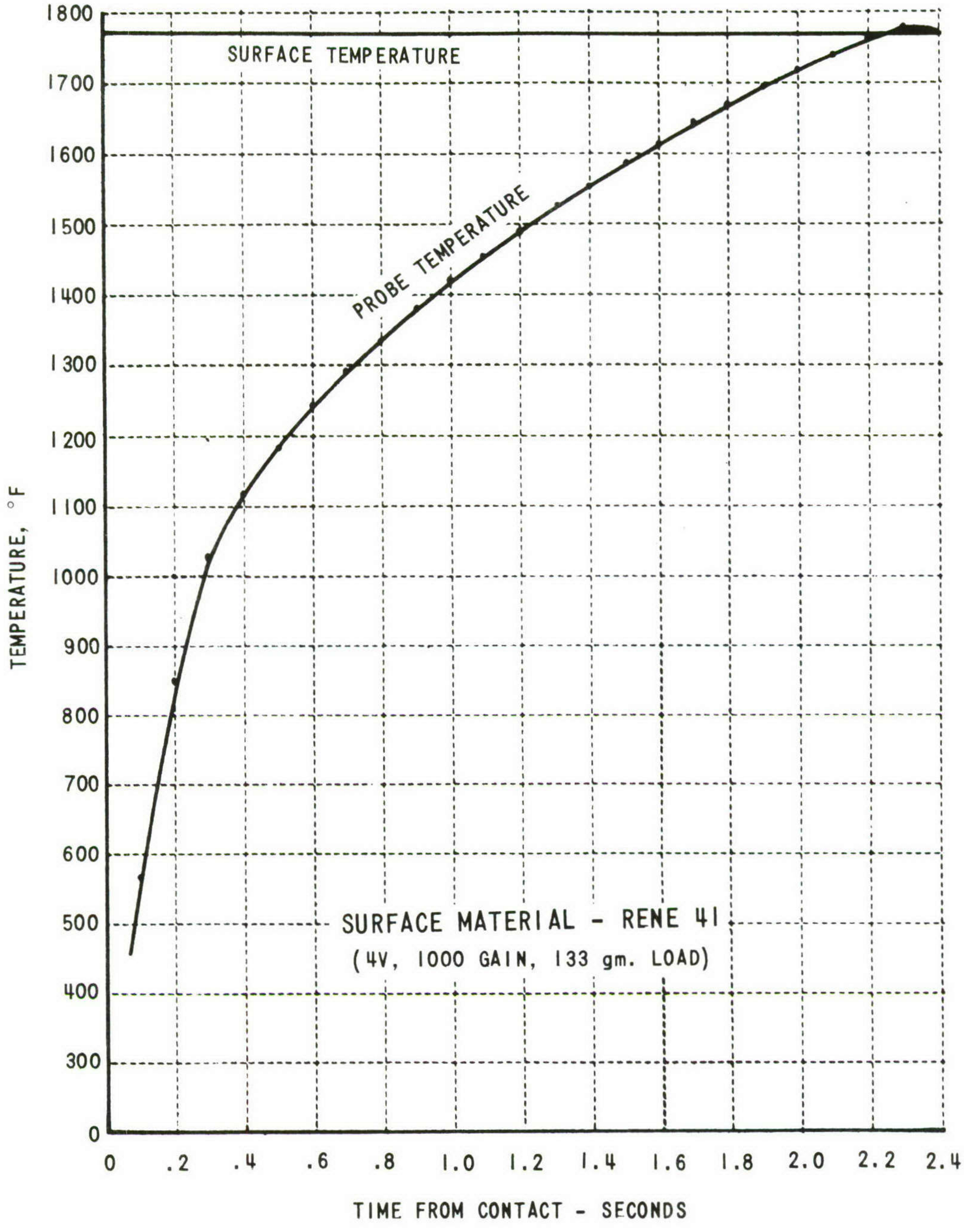

Figure 12 TIME RESPONSE OF PROBE X-11

the tables as Runs 32 through 39 (starting on page 43). In these tests, four hours of testing in 8 half hour increments were completed at an average temperature of over 2100°F without any difficulty. The first three runs did show some deviation but most of the descrepancy is believed to be caused by the gradient through the alumina due to transient conditions. The last 5 half hour periods were at reasonably constant temperatures and produced very little deviation.

The tests on Rene 41 are reported in Runs 7 through 16 (starting on page 28). In Runs 7 and 8, one hour of total time in 2 half hour increments was accumulated at temperatures up to 2186°F. At the end of the second run the probe adhered to the Rene 41 and became inoperable. A new probe was made and used in Runs 9 through 16. In these tests, 4 hours of total time in 8 half hour increments was accumulated. In these tests, the maximum temperature did not exceed 2069°F and no adherence problem was encountered.

6. Other Observations

In discussing accuracy performance, several other items have been mentioned which can affect the performance of the probe. These include contact pressure, adherence and surface deterioration of the test plate in air.

During all of the tests, contact pressure was controlled and varied. Initially a load of 567 grams was used. This was lowered to 267 grams and then 133 grams was used with good success. These various pressures were tried for two reasons:

1. Test plates were being deformed at high temperatures.
2. After 30 minutes of continuous contact with a load of 567 grams, a probe adhered to the stainless steel test plate.

Loads as low as 133 grams produce accuracies within the goals of the program but it is not yet known if these pressures alleviate the adherence problem. If not, still lower loads should be tried. As a matter of fact, lower loads should be tested in any case because the probe is capable of operating at temperatures beyond the ability of some test materials to withstand the stresses.

No effect of surface deterioration on probe performance has been found. During the testing, titanium and stainless steel deteriorated badly. In addition, zirconium oxidized to some extent and was pitted. The disil coated metals were in good condition after test. As previously mentioned, rhodium caps (1 mil thick) were used on probes which were used for disil coated surfaces. Initially, the operation was successful, but at temperatures above 2000°F, the disil apparently flowed around the cap and attacked the platinum sensor. It is hoped this can be avoided by "cupping" the cap to prevent such contact.

In the experimental set-up, the leads from the probe to the temperature recorder and power controller were 6 feet long. For many applications, it may be desirable to have longer leads, therefore, tests were completed in which 50 foot long leads were used. The results showed no effect on accuracy and a small increase in the time response.

TABLES OF TEST RESULTS

Tables of the test results comprise the remainder of the report. They are included in this report for the reader who wants specific details concerning the basis for the remarks made previously about the accuracy and response of the probe system.

Each table number includes all of the runs made on any individual surface material. They are listed in the following order: 1. Stainless Steel, 2. Titanium, 3. Rene 41, 4. Alumina, 5. Disil Coated Molybdenum, 6. Disil Coated Columbium, 7. Zirconium and 8. Quartz.

Each run in the tables shows the conditions under which the tests were made. For example on page 28, the last sub table is headed: Run 7, Rene 41, Probe X-10, 1000 gain, 4v, 133 grams, 0 amps. This means that it was the 7th run on Rene 41 and that the 10th probe of the X series was used. A gain of 1000 was set on the power controller with 4 volts from the battery, 133 grams of weight at the probe tip, and zero amps of threshold current.

The individual columns are probably self explanatory. Times are seconds or minutes from contact and the deviation is simply the difference between the probe and plate temperatures. A minus in the deviation indicates that the probe is reading lower than the plate.

Table 1

Tests On Stainless Steel

Run 1, Stainless Steel, Probe X-1

Time Sec.	Plate °F	Probe °F	Deviation °F
1	1049	877	-172
2	1049	969	-80
3	1049	999	-50
4	1049	1019	-30
5	1049	1026	-23
15	1055	1055	0
30	1055	1057	2
60	1065	1069	4

Run 2, Stainless Steel, Probe X-1

Time Sec.	Plate °F	Probe °F	Deviation °F
1	1482	1400	-82
2	1482	1445	-37
3	1482	1466	-16
4	1482	1476	-6
5	1482	1480	-2
15	1488	1495	7
30	1498	1504	6
60	1522	1531	9

Run 3, Stainless Steel, Probe X-1

Time Sec.	Plate °F	Probe °F	Deviation °F
1	2010	1684	-326
1.7	2010	1980	-30
3	2011	1990	-21
4	2011	2000	-11
5	2012	2003	-9

Table 1 (Cont.)

Tests On Stainless Steel

Run 4, Stainless Steel, Probe X-1

Time Sec.	Plate °F	Probe °F	Deviation °F
1	2262	2115	-147
2	2262	2215	-47
3	2262	2230	-32
4	2262	2240	-22
5	2262	2247	-15
15	2262	2262	0
30	2262	2262	0
60	2262	2266	4

Run 5, Stainless Steel, Probe X-1

Time Sec.	Plate °F	Probe °F	Deviation °F
15	990	982	-1
30	990	992	2
60	990	996	6

Table 1 (Cont.)

Tests On 316 Stainless Steel

Run 6, 316 Stainless Steel, Probe X-1, 560 gain, 6v, 1.5 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
1	2070	2070	0
2	2089	2089	0
3	2089	2088	-1
4	2080	2080	0
5	2080	2080	0
6	2088	2085	-3
7	2090	2088	-2
8	2100	2098	-2
9	2073	2073	0
10	2061	2060	-1
11	2058	2058	0
12	2053	2053	0
13	2049	2049	0
14	2049	2049	0
15	2041	2040	-1
16	2048	2047	-1
17	2051	2050	-1
18	2053	2051	-2
19	2054	2052	-2
20	2057	2055	-2
21	2061	2061	0
22	2064	2063	-1
23	2068	2067	-1
24	2073	2073	0
25	2073	2073	0
26	2080	2080	0
27	2087	2086	-1
28	2091	2091	0
29	2092	2090	-2
30	2097	2097	0

Table 2

Tests On Titanium

Run 1, Titanium, Probe X-3, 1000 gain, 567 grams

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1034	1034	0
30	1046	1046	0
60	1065	1067	2

Run 2, Titanium, Probe X-3, 1000 gain, 567 grams

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1508	1510	2
30	1522	1522	0
60	1533	1533	0

Run 3, Titanium, Probe X-3, 1000 gain, 567 grams

Time Sec.	Plate °F	Probe °F	Deviation °F
15	2069	2059	-10
30	2079	2072	-7
60	2095	2094	-1

Table 3

Tests On Rene 41

Run 1, Rene 41, Probe X-4, 1000 gain, 4v, 567 grams

Time Sec.	Plate °F	Probe °F	Deviation °F
1	1058	890	-168
1.5	1058	1023	-35
3	1059	1033	-26
4	1059	1042	-17
5	1060	1047	-13
15	1065	1065	0
30	1074	1074	0
60	1089	1091	2

Run 2, Rene 41, Probe X-4, 1000 gain, 4v, 267 grams

Time Sec.	Plate °F	Probe °F	Deviation °F
1	1094	1046	-48
2	1094	1067	-27
3	1094	1075	-19
4	1094	1081	-13
5	1094	1085	-9
15	1089	1089	0
30	1076	1076	0
60	1082	1084	2

Run 3, Rene 41, Probe X-4, 1000 gain, 4v, 567 grams

Time Sec.	Plate °F	Probe °F	Deviation °F
1	1476	1365	-111
2	1476	1427	-49
3	1476	1441	-35
4	1476	1451	-25
5	1476	1455	-21
15	1486	1476	-10
30	1493	1489	-4

Table 3 (Cont.)

Tests On Rene 41

Run 4, Rene 41, Probe X-4, 1000 gain, 4v, 567 grams

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1477	1473	-4
30	1483	1480	-3
60	1483	1482	-1

Run 5, Rene 41, Probe X-4, 1000 gain, 4v, 267 grams

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1495	1490	-5
30	1496	1492	-4
60	1496	1495	-1

Run 6, Rene 41, Probe X-4, 1000 gain, 4v, 567 grams

Time Sec.	Plate °F	Probe °F	Deviation °F
15	2082	2069	-13
30	2082	2069	-13
60	2085	2070	-15

Run 7, Rene 41, Probe X-10, 1000 gain, 4v, 133 grams, 0 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	2012	1999	-13
1.0	2010	2002	-8
5.0	2027	2036	9
10.0	2056	2064	8
15.0	2061	2064	3
20.0	2078	2086	8
25.0	2102	2105	3
30.0	2103	2109	6

Table 3 (Cont.)

Tests On Rene 41

Run 8, Rene 41, Probe X-10, 1000 gain, 4v, 133 grams, 0 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	2129	2145	16
1.0	2134	2143	9
5.0	2133	2137	4
10.0	2141	2141	0
15.0	2148	2152	3
20.0	2167	2167	0
25.0	2176	2178	2
30.0	2186	2186	0

Run 9, Rene 41, Probe X-11, 1000 gain, 4v, 133 grams, 1/4 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	2010	2007	-3
1.0	2012	2010	-2
5.0	2010	2010	0
10.0	2040	2040	0
15.0	2044	2039	-5
20.0	2052	2049	-3
25.0	2049	2048	-1
30.0	2054	2054	0

Run 10, Rene 41, Probe X-11, 1000 gain, 4v, 133 grams, 1/4 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	2044	2040	-4
1.0	2039	2035	-4
5.0	2035	2032	-3
10.0	2037	2037	0
15.0	2043	2043	0
20.0	2049	2049	0
25.0	2051	2051	0
30.0	2059	2059	0

Table 3 (Cont.)

Tests On Rene 41

Run 11, Rene 41, Probe X-11, 1000 gain, 4v, 133 grams, 1/4 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	2043	2036	-7
1.0	2035	2029	-6
5.0	2031	2031	0
10.0	2027	2027	0
15.0	2027	2027	0
20.0	2024	2024	0
25.0	2023	2023	0
30.0	2024	2024	0

Run 12, Rene 41, Probe X-11, 1000 gain, 4v, 133 grams, 1/4 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	2047	2048	1
1.0	2043	2036	-7
5.0	2040	2040	0
10.0	2068	2066	-2
15.0	2050	2048	-2
20.0	2045	2044	-1
25.0	2050	2050	0
30.0	2050	2050	0

Run 13, Rene 41, Probe X-11, 1000 gain, 4v, 133 grams, 1/4 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	2001	2003	2
1.0	1998	2001	3
5.0	2011	2010	-1
10.0	2014	2013	-1
15.0	2006	2000	-6
20.0	2010	2007	-3
25.0	2023	2015	-8
30.0	2036	2033	-3

Table 3 (Cont.)

Tests On Rene 41

Run 14, Rene 41, Probe X-11, 1000 gain, 4v, 133 grams, 1/4 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	2044	2037	-7
1.0	2037	2026	-11
5.0	2018	2011	-7
10.0	2015	2010	-5
15.0	2018	2012	-6
20.0	2019	2014	-5
25.0	2022	2018	-4
30.0	2027	2023	-4

Run 15, Rene 41, Probe X-11, 1000 gain, 4v, 133 grams, 1/4 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	2041	2036	-5
1.0	2040	2034	-6
5.0	2038	2034	-4
10.0	2039	2036	-3
15.0	2041	2039	-2
20.0	2048	2044	-4
25.0	2052	2049	-3
30.0	2054	2052	-2

Run 16, Rene 41, Probe X-11, 1000 gain, 4v, 133 grams, 1/4 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	2056	2049	-7
1.0	2047	2041	-6
5.0	2056	2053	-3
10.0	2062	2060	-2
15.0	2065	2062	-3
20.0	2069	2066	-3
25.0	2070	2068	-2
30.0	2069	2067	-2

Table 4

Tests On Alumina

Run 1, Alumina, Probe X-4, 1000 gain, 4v, 267 grams, 2 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
1	1015	833	-182
2	1013	969	-44
3	1012	959	-53
4	1012	987	-25
5	1012	995	-17
10	1012	1020	8
15	1033	1033	0
30	1039	1039	0
60	1052	1054	2

Run 2, Alumina, Probe X-4, 1000 gain, 4v, 267 grams, 2 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
1	1430	1171	-259
2	1429	1232	-197
3	1429	1338	-91
4	1429	1366	-63
5	1427	1380	-47
10	1436	1411	-25
15	1423	1420	-3
30	1420	1420	0
60	1411	1417	6

Run 3, Alumina, Probe X-4, 1000 gain, 4v, 267 grams, 2 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
1	1983	1454	-529
2	1983	1844	-139
3	1982	1906	-76
4	1982	1922	-60
5	1981	1940	-41
10	1985	1971	-14
15	1985	1985	0
30	1970	1978	8
60	1969	1977	8

Table 4 (Cont.)

Tests On Alumina

Run 4, Alumina, Probe X-4, 1000 gain, 4v, 267 grams, 2 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
1	1460	1086	-354
2	1460	1327	-133
3	1460	1383	-77
4	1460	1392	-68
5	1460	1414	-46
10	1460	1454	-6
15	1458	1463	5
30	1461	1471	10
60	1467	1487	20

Run 5, Alumina, Probe X-4, 1000 gain, 4v, 567 grams, 2 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
1	1047	797	-250
2	1047	991	-56
3	1047	991	-56
4	1047	1008	-39
5	1047	1015	-32
6	1047	1025	-22
7	1047	1030	-17
8	1047	1036	-11
9	1047	1038	-9
10	1047	1046	-1
15	1047	1047	0
30	1047	1051	4
60	1046	1052	6

Table 4 (Cont.)

Tests On Alumina

Run 6, Alumina, Probe X-4, 1000 gain, 4v, 267 grams, 2 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
1	1038	735	-303
2	1038	979	-59
3	1038	972	-66
4	1038	997	-41
5	1038	1008	-30
6	1038	1015	-23
7	1038	1020	-18
8	1038	1028	-10
9	1038	1030	-8
10	1038	1034	-4
15	1038	1039	1
30	1038	1047	9
60	1038	1052	14

Run 7, Alumina, Probe X-4, 1000 gain, 4v, 267 grams, 2 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
1	1446	1170	-276
2	1446	1380	-66
3	1446	1383	-63
4	1446	1408	-38
5	1446	1418	-28
6	1446	1427	-19
8	1446	1439	-7
10	1446	1445	-1
15	1446	1454	8
30	1445	1454	9
60	1439	1454	15

Table 4 (Cont.)

Tests On Alumina

Run 8, Alumina, Probe X-4, 1000 gain, 4v, 267 grams, 2 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
1	2051	1667	-384
2	2051	1865	-186
3	2051	1957	-94
4	2049	1979	-70
5	2049	1995	-54
6	2049	2008	-41
8	2049	2020	-29
10	2048	2028	-20
12	2048	2031	-17
15	2048	2036	-12
30	2043	2040	-3
60	2043	2043	0

Run 9, Alumina, Probe X-4, 1000 gain, 4v, 567 grams, 2 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
1	2032	1694	-338
2	2031	1884	-147
3	2030	1930	-100
4	2030	1962	-68
5	2028	1977	-51
6	2028	1989	-39
8	2027	2001	-26
10	2026	2008	-18
15	2024	2015	-9
30	2020	2018	-2
60	2023	2019	-4

Table 4 (Cont.)

Tests On Alumina

Run 10, Alumina, Probe X-4, 1000 gain, 4v, 567 grams, 2 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
1	1477	1190	-287
2	1477	1392	-85
3	1476	1410	-66
4	1476	1427	-49
5	1476	1445	-31
6	1474	1455	-19
7	1474	1460	-14
8	1473	1470	-3
10	1471	1471	0
15	1471	1474	3
30	1465	1477	12
60	1465	1480	15

Run 11, Alumina, Probe X-4, 1000 gain, 4v, 267 grams, 2 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
1	1025	711	-314
2	1025	966	-59
3	1025	966	-59
4	1025	987	-38
5	1025	997	-28
6	1025	1004	-21
8	1025	1015	-10
10	1025	1021	-4
15	1025	1026	1
30	1026	1030	4
60	1025	1036	11

Table 4 (Cont.)

Tests On Alumina

Run 12, Alumina, Probe X-5, 1000 gain, 4v, 133 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1086	1086	0
30	1086	1086	0
60	1073	1076	3

Run 13, Alumina, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1086	1086	0
30	1086	1086	0
60	1073	1076	3
120	1067	1073	6

Run 14, Alumina, Probe X-5, 1000 gain, 4v, 533 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1086	1086	0
30	1084	1084	0
60	1075	1078	3
120	1070	1073	3

Run 15, Alumina, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1514	1514	0
30	1517	1518	1
60	1521	1521	0

Table 4 (Cont.)

Tests On Alumina

Run 16, Alumina, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	2041	2029	-12
30	2041	2037	-4
60	2041	2041	0

Run 17, Alumina, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1828	1817	-11
30	1828	1821	-7
60	1826	1821	-5

Run 18, Alumina, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1780	1772	-8
30	1784	1780	-4
60	1788	1788	0

Run 19, Alumina, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1650	1644	-6
30	1650	1650	0
60	1650	1650	0

Table 4 (Cont.)

Tests On Alumina

Run 20, Alumina, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1547	1547	0
30	1549	1548	0
60	1556	1556	0

Run 21, Alumina, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1381	1381	0
30	1389	1389	0
60	1396	1396	0

Run 22, Alumina, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1274	1274	0
30	1278	1278	0
60	1280	1280	0

Run 23, Alumina, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1181	1181	0
30	1185	1188	3
60	1193	1195	2

Table 4 (Cont.)

Tests On Alumina

Run 24, Alumina, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1105	1105	0
30	1115	1115	0
60	1115	1115	0

Run 25, Alumina, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	889	889	0
30	889	889	0
60	889	889	0

Run 26, Alumina, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	776	776	0
30	776	776	0
60	776	776	0

Run 27, Alumina, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	666	666	0
30	664	664	0

Table 4 (Cont.)

Tests On Alumina

Run 28, Alumina, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	469	469	0
30	469	473	4
60	471	475	4

Run 29, Alumina, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	545	549	4
30	547	553	6

Table 4 (Cont.)

Tests On Alumina

Run 30, Alumina, Probe X-4, 1000 gain, 4v, 267 grams

Time Min.	Plate °F	Probe °F	Deviation °F
2	703	745	42
4	859	901	42
6	992	1025	33
8	1146	1178	32
10	1362	1401	39
12	1570	1606	36
14	1710	1738	28
16	1817	1837	20
18	1893	1909	16
20	1961	1971	10
22	2099	2099	0
24	2229	2229	0
26	2323	2317	-6
28	2399	2392	-7
30	2514	2514	0
32	2620	2620	0
34	2686	2686	0

Table 4 (Cont.)

Tests On Alumina

Run 31, Alumina, Probe X-9, 1000 gain, 4v, 267 grams

Time Min.	Plate °F	Probe °F	Deviation °F
1	2000	1996	-4
3.5	2108	2117	9
6	2297	2297	0
8	2442	2436	-6
10	2582	2575	-7
12.5	2721	2718	-3
14.0	2784	2792	8
15.0	2823	2832	9
17.0	2909	2935	26
18.5	2968	2994	26

Run 32, Alumina, Probe X-10, 1000 gain 4v, 133 grams, 0 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	1788	1800	12
1.0	1795	1803	8
5.0	1936	1954	18
10.0	2036	2052	16
15.0	2063	2075	12
20.0	2083	2095	12
25.0	2106	2116	10
30.0	2132	2139	7

Table 4 (Cont.)

Tests On Alumina

Run 33, Alumina, Probe X-10, 1000 gain, 4v, 133 grams, 0 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	1985	1996	11
1.0	1970	1985	15
5.0	2012	2024	12
10.0	2045	2055	10
15.0	2052	2060	8
20.0	2076	2085	9
25.0	2085	2089	4
30.0	2102	2104	2

Run 34, Alumina, Probe X-10, 1000 gain, 4v, 133 grams, 0 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	2023	2028	5
1.0	2010	2016	6
5.0	2036	2047	11
10.0	2065	2074	9
15.0	2077	2081	4
20.0	2102	2113	11
25.0	2089	2094	5
30.0	2099	2103	4

Run 35, Alumina, Probe X-10, 1000 gain, 4v, 133 grams, 0 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	2136	2128	-8
1.0	2128	2131	3
5.0	2132	2133	1
10.0	2141	2143	2
15.0	2134	2134	0
20.0	2137	2137	0
25.0	2138	2138	0
30.0	2142	2142	0

Table 4 (Cont.)

Tests On Alumina

Run 36, Alumina, Probe X-10, 1000 gain, 4v, 133 grams, 0 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	2295	2182	-13
1.0	2188	2180	-8
5.0	2167	2167	0
10.0	2158	2158	0
15.0	2154	2154	0
20.0	2154	2154	0
25.0	2154	2154	0
30.0	2154	2154	0

Run 37, Alumina, Probe X-10, 1000 gain, 4v, 133 grams, 0 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	2180	2169	-11
1.0	2169	2169	0
5.0	2165	2165	0
10.0	2165	2165	0
15.0	2164	2164	0
20.0	2160	2160	0
25.0	2158	2158	0
30.0	2158	2158	0

Run 38, Alumina, Probe X-10, 1000 gain, 4v, 133 grams, 0 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	2049	2047	-2
1.0	2047	2052	5
5.0	2061	2062	1
10.0	2087	2090	3
15.0	2115	2119	4
20.0	2138	2143	5
25.0	2167	2167	0
30.0	2184	2184	0

Table 4 (Cont.)

Tests On Alumina

Run 39, Alumina, Probe X-10, 1000 gain, 4v, 133 grams, 0 amps.

Time Min.	Plate °F	Probe °F	Deviation °F
0.5	2216	2205	-11
1.0	2208	2208	0
5.0	2208	2208	0
10.0	2220	2220	0
15.0	2232	2232	0
20.0	2237	2237	0
25.0	2245	2245	0
30.0	2249	2249	0

Table 5

Tests On Disil Coated Molybdenum

Run 1, Disil Coated Molybdenum, Probe X-5, 1000 gain, 4 v, 133 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1021	1028	7
30	1025	1028	3
60	1028	1036	8

Run 2, Disil Coated Molybdenum, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1060	1060	0
30	1060	1060	0
60	1060	1062	2

Run 3, Disil Coated Molybdenum, Prove X-5, 1000 gain, 4v, 133 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1477	1483	6
30	1477	1483	6
60	1485	1489	4

Run 4, Disil Coated Molybdenum, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1534	1534	0
30	1541	1541	0
60	1547	1547	0

Table 5 (Cont.)

Tests On Disil Coated Molybdenum

Run 5, Disil Coated Molybdenum, Probe X-5, 1000 gain, 4v, 133 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	2032	2032	0
30	2032	2032	0
60	2036	2036	0

Run 6, Disil Coated Molybdenum, Probe X-5, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	2090	2079	-11
30	2090	2083	-7
60	2092	2089	-3

Table 6

Tests On Disil Coated Columbium

Run 1, Disil Coated Columbium, Probe X-6, 1000 gain, 4v, 133 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1003	999	-4
30	1007	1007	0
60	1017	1021	4

Run 2, Disil Coated Columbium, Probe X-6, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1105	1105	0
30	1108	1110	2
60	1110	1111	1

Run 3, Disil Coated Columbium, Probe X-6, 1000 gain, 4v, 133 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1467	1467	0
30	1468	1468	0
60	1465	1465	0

Run 4, Disil Coated Columbium, Probe X-8, 1000 gain, 4v, 133 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1825	1820	-5
30	1824	1824	0
60	1829	1846	17
120	1944	1970	26
180	2018	2036	18
240	2134	2156	22
300	2214	2229	15
360	2272	2281	9

Table 7

Tests On Zirconium

Run 1, Zirconium, Probe X-8, 1000 gain, 4v, 133 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1004	1004	0
30	1013	1018	5
60	1028	1033	5

Run 2, Zirconium, Probe X-8, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1052	1052	0
30	1060	1060	0
60	1064	1064	0

Run 3, Zirconium, Probe X-8, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1505	1511	6
30	1518	1518	0
60	1508	1508	0

Run 4, Zirconium, Probe X-8, 1000 gain, 4v, 133 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	2023	2023	0
30	2019	2026	7
60	2016	2026	10

Table 7 (Cont.)

Tests On Zirconium

Run 5, Zirconium, Probe X-8, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	2035	2035	0
30	2032	2037	5
60	2028	2036	8

Run 6, Zirconium, Probe X-8, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1724	1705	-19
30	1717	1717	0
60	1706	1706	0

Run 7, Zirconium, Probe X-8, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1597	1582	-15
30	1596	1592	-4
60	1596	1596	0

Run 8, Zirconium, Probe X-8, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1287	1269	-18
30	1289	1287	-2
60	1287	1287	0

Table 7 (Cont.)
Tests On Zirconium

Run 9, Zirconium, Probe X-8, 1000 gain, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1258	1240	-18
30	1252	1244	-8
60	1244	1244	0

Run 10, Zirconium, Probe X-8, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	1162	1152	-10
30	1163	1154	-9
60	1159	1159	0

Run 11, Zirconium, Probe X-8, 4v, 267 grams, 1.5 amps.

Time Sec.	Plate °F	Probe °F	Deviation °F
15	968	964	-4
30	966	966	0
60	964	964	0

Table 8

Tests On Quartz

Run 1, Quartz, Probe X-4, 1000 gain, 4v, 567 grams, 2 amps.

Time Sec.	Rear Plate °F	Front Plate °F	Probe °F	Deviation Rear °F	Deviation Front °F
1	1015	1021	630	-385	-391
2	1015	1021	845	-170	-176
3	1015	1021	865	-150	-156
4	1015	1021	898	-117	-123
5	1015	1021	919	-96	-102
6	1015	1023	931	-84	-92
8	1015	1025	956	-59	-69
10	1015	1025	974	-41	-51
12	1015	1025	987	-28	-38
14	1017	1026	992	-25	-34
16	1017	1028	999	-18	-29
18	1017	1028	1005	-12	-23
20	1018	1028	1008	-10	-20
30	1026	1030	1021	-5	-9
60	1039	1034	1039	0	5

Table 8 (Cont.)

Tests On Quartz

Run 2, Quartz, Probe X-4, 1000 gain, 4v, 567 grams, 2 amps.

Time Sec.	Rear Plate °F	Front Plate °F	Probe °F	Deviation Rear °F	Deviation Front °F
1	1485	1508	1038	-447	-470
2	1486	1509	1244	-242	-255
3	1486	1509	1301	-185	-208
4	1486	1511	1338	-148	-173
5	1488	1512	1366	-122	-146
6	1488	1512	1389	-99	-123
8	1489	1514	1420	-69	-86
10	1490	1515	1442	-48	-73
12	1490	1515	1454	-36	-61
14	1490	1517	1463	-27	-54
16	1492	1518	1471	-21	-47
18	1495	1521	1477	-18	-44
20	1496	1521	1483	-13	-38
30	1502	1530	1498	-4	-42
60	1521	1533	1525	4	-8

Table 8 (Cont.)

Tests On Quartz

Run 3, Quartz, Probe X-4, 1000 gain, 4v, 567 grams, 2 amps.

Time Sec.	Rear Plate °F	Front Plate °F	Probe °F	Deviation Rear °F	Deviation Front °F
1	1824	1843	1353	-471	-490
2	1824	1843	1564	-260	-279
3	1824	1843	1630	-194	-213
4	1824	1843	1664	-160	-179
5	1824	1843	1696	-128	-147
6	1824	1843	1715	-109	-128
8	1825	1843	1747	-78	-96
10	1826	1844	1765	-61	-79
12	1828	1844	1780	-48	-64
14	1829	1846	1788	-41	-58
16	1829	1846	1796	-33	-50
18	1829	1847	1800	-29	-47
20	1831	1847	1807	-24	-40
30	1836	1850	1821	-15	-29
60	1841	1856	1836	-5	-20

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This report describes the design, operation and performance of a probe system with which temperatures can be measured quickly and accurately on a variety of surfaces. In operation, the probe is touched to a surface and through its own sensor, heater, and electronic servo system, is automatically adjusted to the undisturbed surface temperature. Extensive testing on a variety of materials (including alumina, stainless steel, titanium, Rene 41, disil coated molybdenum, disil coated columbium, zirconium, and quartz) has shown generally to have an accuracy of better than 1/2%. The highest temperature measured successfully in intermittent steady state tests was about 2450°F (1343°C) and in transient tests was 2994°F (1645°C).

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CALIBRATION* OF 3000°F PROBES

Probe No.	Gain	Volts	Threshold Setting Amps.	Plate Temp. °F	Probe Temp. °F	Error °F
1	2000	4	0.00	1650	1654	+4
2	2000	4	0.00	1502	1498	-4
3	1000	4	0.00	1623	1626	+3
4	1000	4	0.00	1613	1609	-4
5	2000	4	0.10	1658	1660	+2
6	1000	4	0.00	1694	1699	+5

*These probes were calibrated under radiation conditions on stainless steel plate in steady state. Temperature readings were taken 15 seconds after contact. Proper threshold setting must be assured when probes are changed to assure proper accuracy.

Adjustment of the Threshold Setting on the Power Controller:

With probe and controller in operating condition (standby switch off and probe at room temperature), momentarily flip standby switch on. Note the movement of the ammeter. For 0.00 amps threshold, there should be very little movement of the meter. If there is or if a different threshold adjustment is needed for the particular probe being used, remove the cover from the controller and adjust the potentiometer (which is to the left of the heat sink on the chassis) until the proper current is obtained on the meter. Make this adjustment while the probe is at room temperature since any power applied to the heater will immediately tend to make the sensor heat and reduce the apparent threshold setting.

Installation of Probe in Holder:

The following is the correct termination of the probe wires to the plug on holder. Caution--do not stress small wires.

Purple - A) error signal to
Green - H) controller

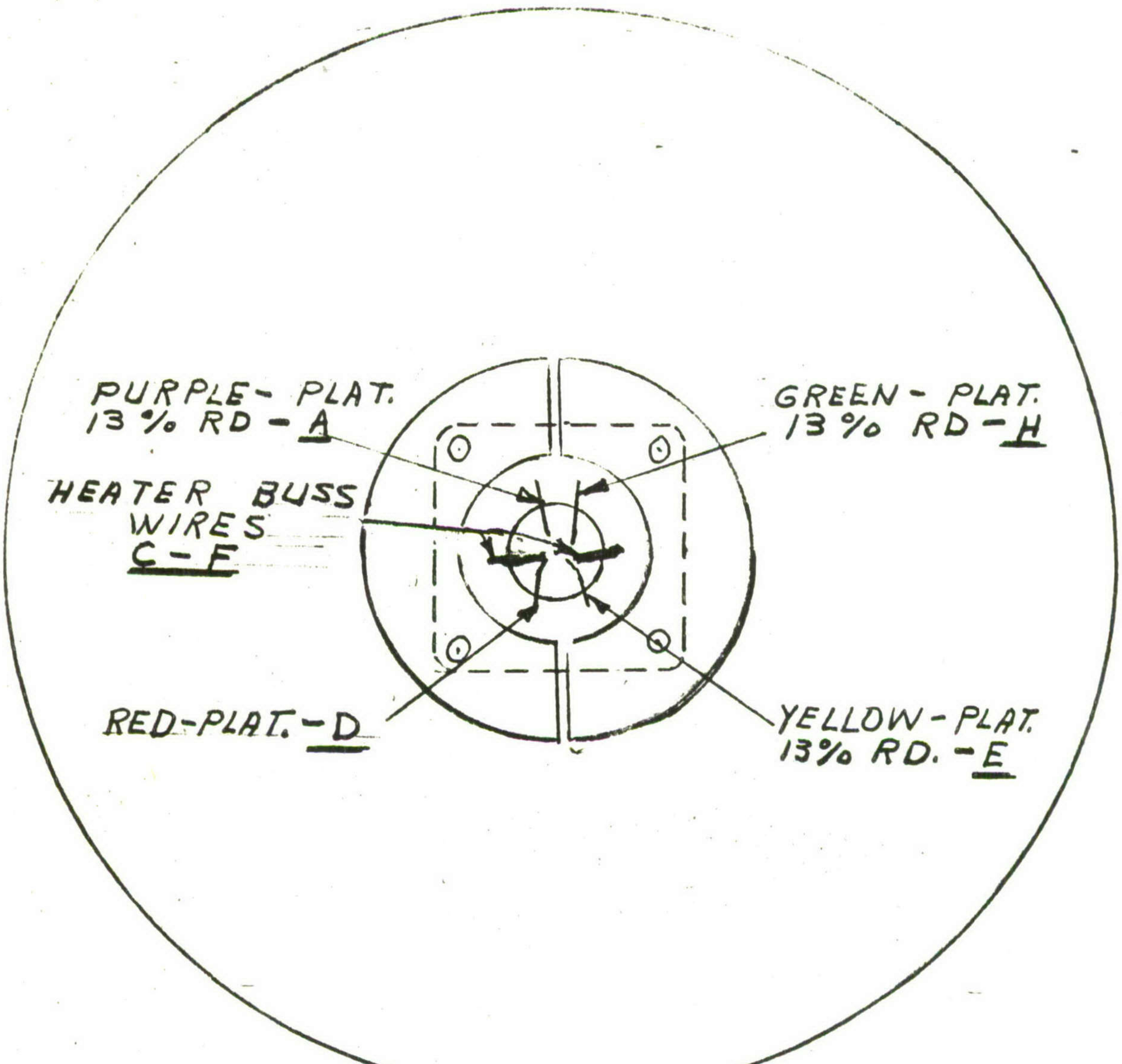
Yellow - E (Pt, 13% Rh)

Red - D (Platinum)

Copper Buss wires C - F

THERMOCOUPLE + HEATER WIRE DIAGRAM SHOWING HOW TO CONNECT WIRES TO AMPHENOL PLUG CONNECTOR

LETTER DESIGNATIONS REFER TO LETTERS WHICH WIRES ARE SOLDERED TO ON AMPHENOL PLUG



TOP VIEW OF PROBE IN COOLING SHEATH - LOOKING FROM HANDLE DOWN

W. E. Alexander/FDTE/36280

(18)

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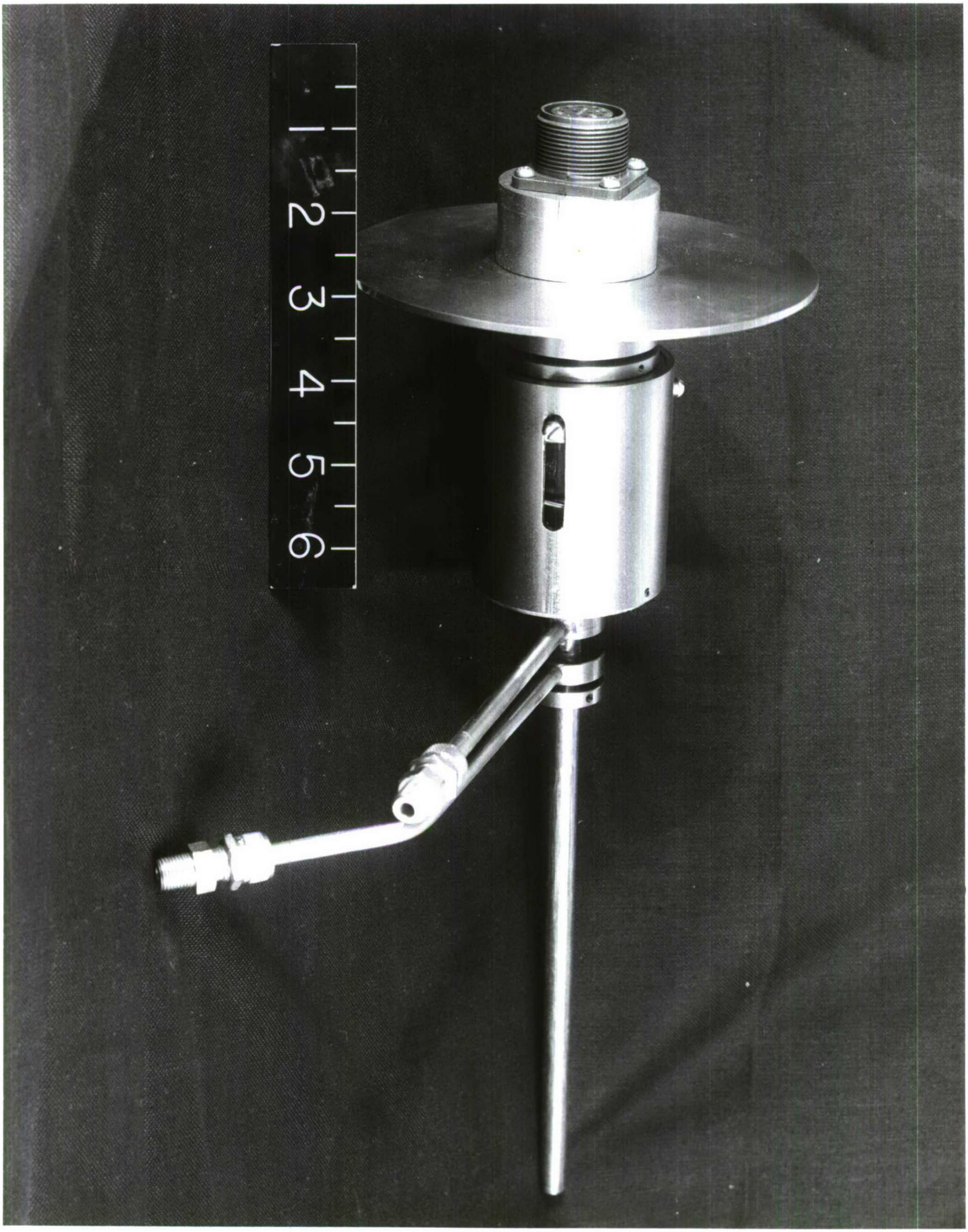
Englehard Industries, Inc. Baker Platinum Division 113 Astor Street Attn: Mr. Erwin C. Winkelmann Newark 14, New Jersey	1
Fairchild Airplane Division Fairchild Engine and Airplane Corporation Hagerstown, Maryland	1
Garrett Corporation AiResearch Manufacturing Co. Attn: Technical Library Los Angeles, California 90009	1
General Electric Company Attn: Mr. R. C. McWilson Louisville, Kentucky	1
Grumman Aircraft Engineering Corp. Engineering Library Bethpage, Long Island, New York	1
High Temperature Instruments Corp. 225 West Lehigh Ave. Attn: Mr. Paul Beckman Philadelphia 33, Pa.	1
Hughes Aircraft Company Florence Avenue at Teal Street Attn: Miss Mary Jo Case Culver City, California	1
Institute of Aeronautical Sciences 2 East 64th Street Attn: Mr. J.J. Clennon, Librarian New York 21, New York	1
Jet Propulsion Laboratory Library, (T. D. S.) 4800 Oak Grove Drive Attn: Mr. N. E. Devereux Pasadena 3, California	2
Leeds & Northrop Company Attn: Technical Library 4901 Stenton Avenue Philadelphia 44, Pa.	1

	Cys
Lockheed Aircraft Corporation Engineering Library Building 63-1, Department 72-25, Plant A-1 Burbank, California	1
Lockheed Aircraft Corporation Structures Testing Burbank, California	1
Lockheed Aircraft Corporation Structures Testing Marietta, Georgia	1
Marquardt Corporation Attn: Mr. R. L. Graupe 16555 Saticoy St. Van Nuys, California	1
Martin Company Configurations Department P.O. Box 2831 Orlando, Florida	1
Martin Marietta Attn: Mr. Jim Hughes Middle River, Maryland	1
Martin Marietta Attn: Mr. Ed. Stephenson Box 179 Mail L-5 Denver, Colorado	1
Massachusetts Institute of Technology Department of Aeronautical Engineering Attn: Dr. J. W. Mar Cambridge 39, Massachusetts	1
McDonnell Aircraft Corporation P.O. Box 516, Municipal Airport Attn: Engineering Library Saint Louis 66, Missouri	1
McMaster University Hamilton College Attn: Mr. Michael B. Ives Hamilton, Ontario, Canada	1

	Cys
Minneapolis-Honeywell Regulator Company Aeronautical Division Minneapolis, Minnesota	1
Mr. Robert J. Moffat 84F Escondido Village Stanford, California 94305	1
Narmco, Incorporated 8125 Aero Drive San Diego, California	1
North American Aviation, Inc. Attn: Structures Laboratory International Airport Los Angeles 45, California	1
North American Aviation, Inc. Space & Information Systems Division Attn: Mr. J. Devereaux Leahy 12214 Lakewood Blvd. Downey, California	2
North American Aviation Structures Test Laboratory Inglewood, California	1
North American Aviation Structures Test Laboratory Columbus, Ohio	1
Northrop Aircraft, Inc. Attn: Librarian Hawthorne, California	2
Republic Aviation Corporation Attn: Mr. Wolden Magann, Senior Group Structures Engineer Farmingdale, Long Island, New York	1
Republic Aviation Corporation Guided Missiles Division 447 Broadway Hicksville, New York	1

	Cys
Ryan Aeronautical Company Lindberg Field San Diego 12, California	1
Space Technology Laboratories Engineering Mechanics Section Inglewood, California	1
University of Michigan Engineering Research Institute Attn: Dr. H. F. Allen Ann Arbor, Michigan	1
Thermo-Electric Company, Inc. Attn: Irene Shuster Saddle Brook, New Jersey	1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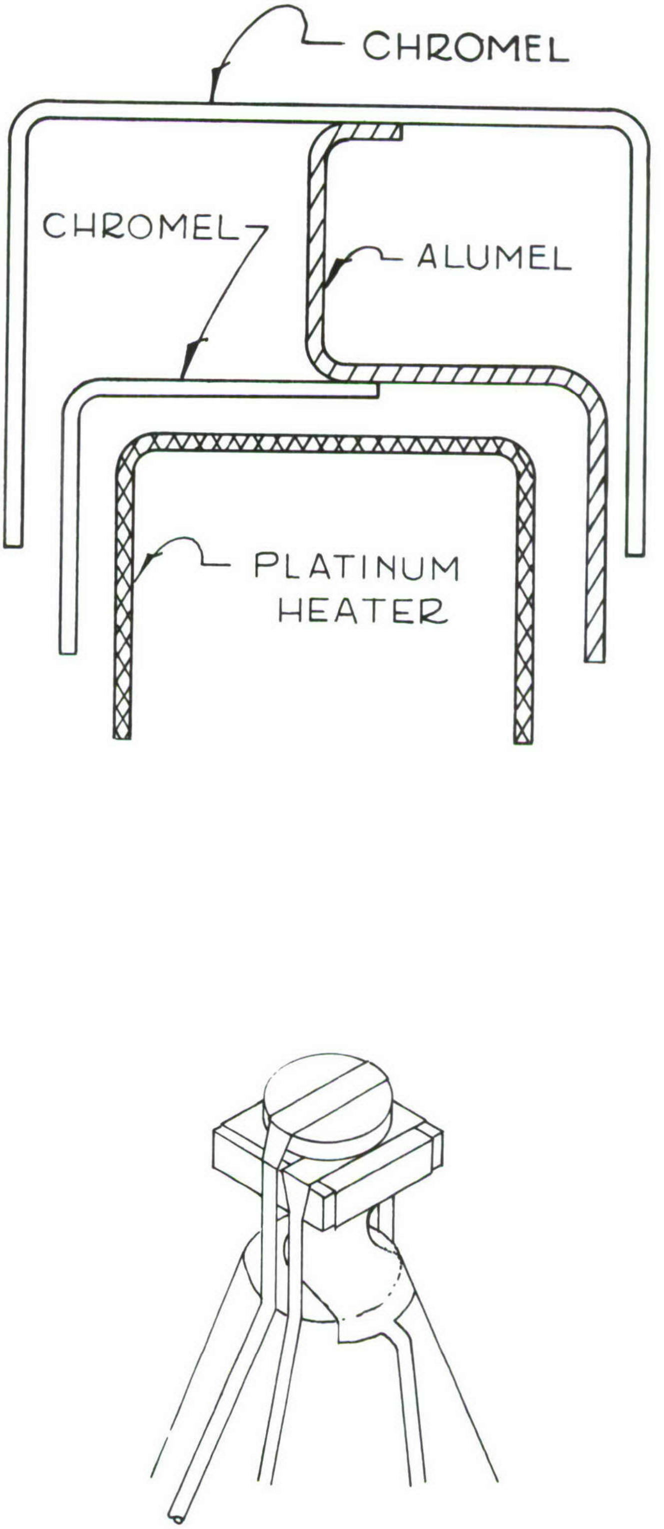


FIG. 2 1,000° F PROBE SENSOR DETAIL

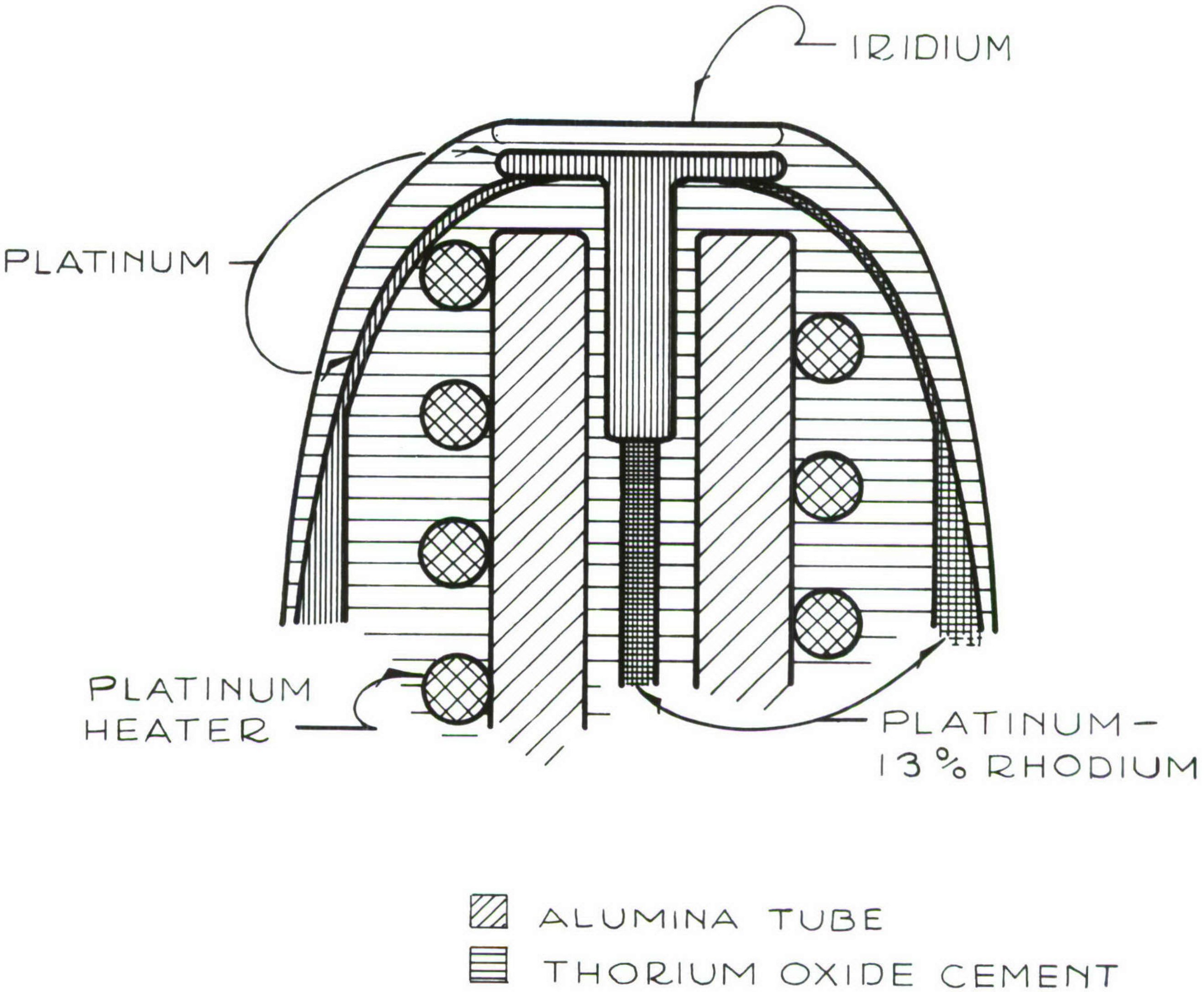
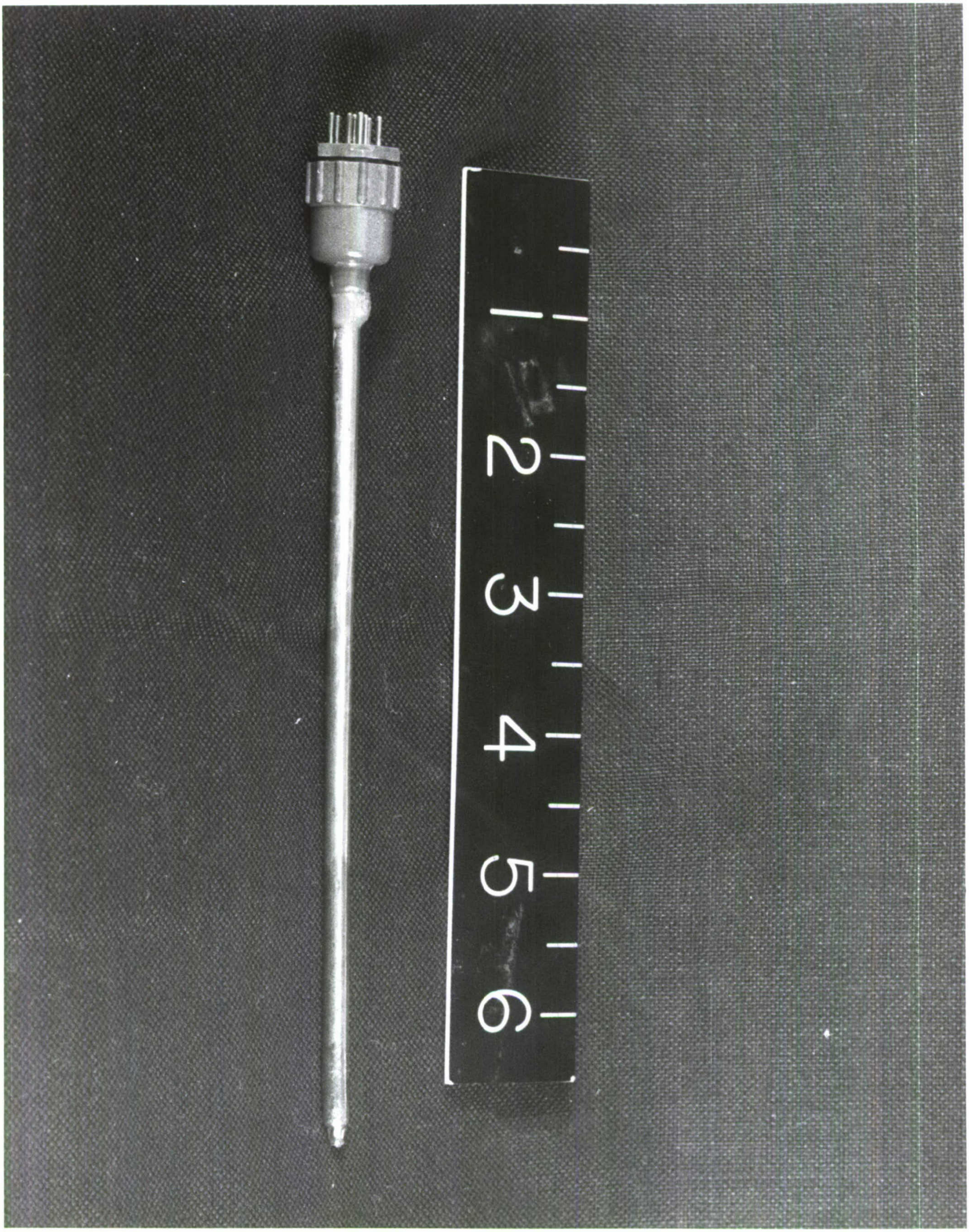


FIG. 3 3,000°F PROBE SENSOR DETAIL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